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MINIMUM MILK REQUIREMENT
FOR CALF RAISING

by

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OUTLINE.

	Page
Introduction.....	1
Review of Literature - Part One.....	4
Calf Feeding.....	4
European Investigations.....	6
American Investigations.....	14
Use of Milk Substitutes in Calf Feeding.....	22
Current Opinion Regarding the Use of Milk Substitutes.....	44
Raising Calves by the Use of a Minimum Amount of Milk.....	50
Review of Literature - Part Two.....	53
Growth.....	53
Nature of Growth.....	56
Internal Secretions.....	59
Nutrition.....	73
Requirements for a Complete Ration.....	74
Energy.....	80
Protein.....	83
Mineral Matter.....	98
Accessory Substances.....	104
Dietary Deficiencies of Some Feeding Stuffs.....	116
Effects of Retarded Growth.....	125
Summary and Practical Application.....	131

	Page
Experimental Work.....	139
Preliminary Experiment.....	140
Outline of the Main Experiment.....	143
Object of the Experiment.....	143
Animals Used.....	145
Rations Used.....	145
Methods of Feeding.....	147
Housing.....	148
Weighing and Measuring.....	149
Discussion of Data.....	150
Growth.....	150
Lot I.....	151
Lot II.....	152
Lot III.....	154
Feed Consumed.....	157
Lot I.....	157
Lot II.....	159
Lot III.....	160
General Summary.....	162
Influence of Breed.....	169
Comparative Cost of Raising Calves.....	170
Conclusions.....	171

INTRODUCTION.

Man in his struggle up the path of civilization came early to know and appreciate the value of milk for food. The primitive tribes which prospered measured their wealth in the size of their herds and flocks. Cattle furnished not only meat for food, and skins to protect the body, but even the wild cattle when they came under domestic influence yielded more milk than was required for raising their young, and this surplus was used as food by their masters. Concern-¹¹⁷ing the importance of milk in the diet, McCollum says, "Milk is worth much more than its energy value or than its protein content would indicate. It is the great factor of safety in making good the deficiencies of the grains which form and must continue to form the principal source of energy in our diet. Without the continued use of milk, not only for the feeding of our children, but in liberal amounts in cookery and as an adjuvant to our diet, we cannot as a nation maintain the position as a world power to which we have arisen. The keeping of dairy animals was the greatest factor in the history of the development of man from a state of barbarism."

Among the problems confronting the dairy farmer, who, according to McCollum, has such an important share in the

welfare of the human race, is the maintenance of his herds. To keep the number of cows in the United States even at its present level requires the raising of four and one-half million animals each year. This appears to be a huge undertaking, but the problem will continue to become even more acute as time goes on. The growing population of the nation means an increasing demand for milk. In addition, there are campaigns now in progress to educate the public as to the value of milk, not only as a food product, but because it is a carrier of an unidentified substance essential for growth and well-being. This work of education extends to the use of milk products, and is creating more demand for butter, skim milk, and cheese. Milk condenseries and cheese factories are growing in number every year, each one clamoring for its full share of raw material.

The mounting cost of feedstuffs has forced up the cost of producing milk, and this increased value of the dairyman's product has added another difficulty to growing calves. Increased cost of production, and the growing demand are factors which tend to raise the price of milk to a point where it cannot be fed to young stock, and the human family threatens to deprive the calf of its natural food. But the cow population must be maintained, both in numbers and efficiency, if dairying is to survive. To replace the cows which have outlived their usefulness, the dairyman must either buy more cows

and heifers, or raise calves from his own cows.

Experience has shown that from a breeding standpoint there can be no progress in a herd where the policy is to replace discarded cows by purchase. If the dairyman chooses to replenish his herd by buying grown stock, it will necessitate the payment of very high prices for cows of known breeding, free from disease. The alternative of buying expensive "good" cows is to buy the culls and throwouts which are always on the market. This practice also involves the additional danger of bringing in such diseases as contagious abortion and tuberculosis with the purchased animals. For the welfare of his herd and the profitable continuation of his business, it behooves the dairyman to raise his own heifer calves, as he has some means of knowing their inherent ability and has the additional assurance that they are disease-free.

The dairyman is keenly interested in knowing how he can raise his calves in an economical and successful manner. This thesis reports the results of several experiments in early weaning and minimum use of milk for calf rearing, which constitute part of a plan for making a thorough study of the problems involved in the early growth and development of dairy heifers. The review of literature embodies a resume of published data on the subject, as well as a survey of what has been written on the newer factors influencing growth and their application to practical feeding operations.

REVIEW OF LITERATURE -- PART ONE.

Calf Feeding.

Accounts of the use of skim milk for calf feeding are found in agricultural literature previous to 1880. Hand skimming was then in vogue, and although this left an appreciable quantity of the butter fat in the skim milk, it had some undesirable features from a calf feeding standpoint. The skim milk was always old and frequently sour when fed to the calves, and in this condition brought on digestive disturbances. This undoubtedly caused much of the dissatisfaction found with early efforts to bring up calves on skim milk. The advent of the centrifugal separator overcame this difficulty of poor quality of the milk, but because of clean skimming, it ushered in the problem of finding a suitable substitute for the butter fat.

Early investigators recognized the importance from a nutritional standpoint of the loss of the fat from the milk by separation, and set about finding a suitable substitute, in order to restore the normal balance of protein and energy. Naturally their quest gave them the choice of using fats and oils, or carbohydrate materials such as starch and sugars. A division for a study of the work could be based upon the

two classes of substitutes used, but because of the difference in the character of materials employed and methods of approaching the problem, it seems preferable to group the investigators on the subject into European and American.

One striking difference between the European and American investigations is that American experiment station workers early conceived the idea of using ordinary grains to supply the energy extracted by removal of the fat, while in Europe the use of starch preparations, oils, emulsions of fats, and various gruels continued long after the problem was well on its way toward a satisfactory solution under American conditions.

Some of the reports cited have no real value in helping to solve the question of adequate supplements for skim milk, but are interesting because they show what a great variety of materials and methods were tried. They are set forth in chronological order and afford a fair idea of the progress toward the solution of this problem, if we may say it has been solved. Early investigations were conducted with limited numbers of animals only and are not so completely and accurately reported as some of the later experiments.

European Investigations - M. Petersen¹⁷⁰ reports the successful use of peanut oil with sour and skim milk. In England, W. Somerville¹⁹² successfully fed boiled linseed oil and cod liver oil as supplements to skim milk. Starch and skim milk was fed by Maswersit,¹³⁶ a German; and Rigaux,¹⁸³ a Belgian, recommended the use of a mixture of flour, malt, carbonate of potash and a little chalk fed in skim milk. Dickson and Malpeaux³² fed a variety of substances in conjunction with skim milk, such as potatoe starch, starch and flaxseed decoction, rice flour, rice flour and flaxseed decoction, malt flour, artificial cream (emulsion of peanut oil, sugar, etc.), and oleomargarine. The malt preparations proved best.

Seton¹⁹⁰ stated that cod liver oil may be used with safety for supplementing separator skim milk for calves and they readily became accustomed to it. Kälberrahm, a commercial feeding stuff, was fed with skim milk by Käppeli¹⁰⁴ but did not give as satisfactory results as whole milk. Moser and Käppeli¹⁴⁶ tested Crema-val, another commercial substitute for milk fat, but it did not prove successful. Linseed meal was one of the first materials used in this country for calf feeding, and in 1902 Guthrie⁶⁶ of New South Wales recommended crushed linseed or linseed meal as the best material for supplementing skim milk in calf feeding. Coconut oil cake, maize meal, oat meal, and linseed cake were also reported on favorably. All these feeds were cooked in water and fed as gruel.

Representing one of the most impractical supplements from an economical standpoint, Rarkin¹⁷⁸ states that eggs are very valuable for supplementing skim milk in calf feeding. Baldassare¹⁰ used meat meal for calf feeding.

A series of experiments are reported from Ireland¹⁰¹ in which cod liver oil and corn meal were used to supplement skim milk. In each case the cod liver oil proved less efficient and more expensive than corn meal. In a short time test of starch, oleomargarine, and ground bone as skim milk supplements, Besana¹³ got the best results with starch. Pirocchi^{172 & 173} carried on experimental work with calves for a period of six years, using skim milk with rice, ground malt, corn meal, linseed oil, peanut oil, sesame oil, oleomargarine, dried blood, eggs, and commercial calf feeds. Skim milk and oleomargarine gave the cheapest gains. According to efficiency the starchy foods ranked; corn meal, starch, rice flour.

According to Mahon,¹³⁴ cod liver oil proved a better supplement for skim milk than pollard, linseed meal, and molasses. Dunstan³⁷ successfully fed cod liver oil in conjunction with skim milk, and he also recommended a cooked mixture of oatmeal, ground linseed meal, linseed cake, and lentils. Rasquin¹⁷⁹ of Belgium studied a long list of skim milk supplements which included meat meal, potatoe starch, flaxseed (alone and with corn meal and with different kinds

of starch), bread, ground grain, eggs, meat powder, calf feeds, sugar, dried blood, and hay tea. The use of a favorite substance in Germany is reported by Hanne,⁷² who obtained satisfactory results by replacing the milk fat with starch inverted with diastasolin.

Misson¹⁴² was making favorable progress when he recommended a gradual substitution of skim milk cooked with some starchy material for whole milk. Corn meal, cassava meal, and a good quality of wheat bran were the substances used. Pirocchi¹⁴³ obtained better results with flour than with corn meal or oleo to replace fat.

In conjunction with starch, Gouin and Andouard⁶⁰ found powdered green bone a valuable constituent of calf feeds.

Palm fat and skim milk gave satisfactory results for Hangel.⁷¹ Hansen,⁷³ on the other hand, reports that starch in the form of starch paste when converted into sugar by the action of a diastatic ferment was valuable for supplementing skim milk. Dornic and Daire³⁴ tried various combinations, and found barley flour, rice flour, and linseed oil were all satisfactory supplements for skim milk. They report, however, that the addition of oil to the ration did not materially improve the quality of the meat nor influence the gains in weight. Malpeaux¹³⁵ used denatured sugar, starch, and a decoction of flaxseed. Diastasolin and skim milk proved cheaper than whole milk in a trial

made by Haselhoff.⁷⁸

Müller and von Wendt¹⁴⁷ also report on diastasolin.
 Wilsdorf²⁰⁶ tried homogenized milk with some success.
 Dolscius³³ obtained good results with linseed cake and starch inverted with diastasolin. The same material was tried by Hittcher.⁸³ Thirty-seven calves, seven and eight days old at the beginning of the test, were started, but only fourteen completed the full period of fifteen weeks. Thiele¹⁹⁵ after three years' experience in the use of denatured starch, reports it to have proven a useful substitute for milk fat in calf feeding.

Cotton seed oil was added to the list of supplements, and Gouin and Andouard⁶¹ found tapioca flour about equal to potatoe starch when used with skim milk. Hendrick⁸¹ fed cod liver oil and cotton seed oil in skim milk, along with meal. Chiesi²¹ and Besana¹⁴ both reported the successful use of margarin and skim milk to replace whole milk. Cassava meal gave favorable results when fed with skim milk by Dechambre.³¹

An emulsion made by heating cocoanut fat and skim milk and passing it through an emulsion drum was fed successfully by Schuppli,¹⁸⁹ but care was required in its preparation. Foulkes, Andrews, and Garnett⁴⁹ found that skim milk supplemented with cod liver oil gave better results than home-made gruels of oatmeal, linseed meal, corn meal, or ground linseed, linseed cake meal, flour, bean meal. Crushed oats was fed in addition.

Wellman²⁰⁴ fed skim milk and diafarin, a malt extract preparation.

In an experiment with sixty calves, Pirocchi¹⁷⁴ fed whole milk for two to three weeks, and then substituted it with skim milk and oleomargarine to one lot, skim milk and diastasolin (a saccharifying substance extracted from malt) to a second lot, and skim milk with levulin (a distillery product having the power of transforming starch into dextrin) to a third. Several calves were sick during the trial and ten were reported as poor feeders. Taking into consideration the work involved in preparing starch paste and emulsifying oleomargarine, it would appear that these were not highly successful substitutes for whole milk.

A porridge made of cassava flour was used with skim milk by Gouin and Andouard.⁶² Edin⁴¹ used a mixture of oat meal and white flour, rye flour, or corn meal, and another of partially hydrolized starch, but both required quite a bit of care in preparation and were fed with skim milk; so from a practical standpoint were of little value.

The later European investigators recognized the value of using larger numbers of animals, and they seem to have gradually adopted the American methods of using home-grown grains in preference to purchased materials and substances which require special preparation before they can

be fed.

On the principle that carbohydrates can take the place of fats in animal nutrition, Kerekes¹⁰⁸ fed skim milk with an emulsion of rye flour. This emulsion was gradually substituted by oatmeal fed dry at about the age of three months.

The Department of Agriculture of Ireland¹⁰² carried on some extensive experiments, and in one trial with 242 calves, compared a standard calf meal made up of one part ground flaxseed, two parts oatmeal, and two parts maize meal, with maize meal alone as a supplement for skim milk. The meals were first boiled or steeped in hot water for about twelve hours. The conclusion was that when separated milk is given, calves can be reared successfully and at considerable less cost on maize meal alone than upon the standard calf meal. This would seem to indicate that the use of a meal containing a relatively high proportion of oil is not necessary when calves have attained the age of from five to six weeks. In a later trial with 116 calves, crushed oats was compared with the same calf meal, and gains made by the use of oats cost 1.1 cts. per pound less than those made with calf meal.

⁵⁵
The Agricultural Gazette of London reports that in four trials excellent results were obtained from the

feeding of separator milk with crushed oats or maize meal as a gruel, and it is stated that if separator milk is available it is doubtful if anything better is needed.

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Voelcker fed five groups of four calves each on whole milk for three weeks, and then nine weeks as follows: Group I. cod liver oil and separator milk; Group II. commercial calf meal according to directions; Group III. gruel of linseed meal and oat meal with separator milk; Group IV. whole milk; Group V. crushed oats fed dry and separator milk. Gains per animal per day were 1.38, 1.24, 1.19, 1.83, and 1.90 lbs., respectively, which would indicate a decided advantage for the dry crushed oats, which also proved to be the cheapest ration.

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The Journal of the Board of Agriculture of London prints under the heading of "Calf Rearing" various systems of feeding calves, arranged to correspond to the type of dairy farming practiced. On the butter-making farms, where skimmed or separated milk is available, its use is recommended, and supplements are listed under the heads of oils and meals. Of the former, cod liver oil is given preference and linseed oil and slaughter-house dripping are also mentioned as practical supplements for skim milk. In speaking of meal substitutes for fat the author states that a great variety of calf meals or cream substitutes has been successfully used but most contain linseed as a prominent ingredient, and that linseed alone

may be used either as boiled whole linseed or in the ground form. In addition, a mixture of linseed meal (2 parts), oatmeal (1 part), rice meal (1 part), and locust bean meal (1 part), all ground as finely as possible, is mentioned; and also the use of crushed oats with separated milk. The article includes a calf dietary, which is rather conservative in the light of present calf feeding methods.

As stated before, some of these experiments supplied nothing of value toward a solution of the problem of substituting the fat in milk, and the technic employed in preparing some of the gruels, teas, and emulsions, placed them far outside the zone of usefulness from the standpoint of the practical calf feeder. However, they furnish a strong contrast to the more direct and successful methods of the American investigators.

American Investigations - One of the features of nearly all early calf feeding experiments was the use of flaxseed or oil meal, often cooked as a gruel, in supplementing the skim milk. Hunt and Zink⁹² in a trial lasting 161 days fed steam-cooked linseed meal with skim milk, in comparison with whole milk and skim milk. All lots had a grain mixture of shelled corn and whole oats in addition. The addition of the gruel did not improve the ration.

Wilson and Curtiss²⁰⁷ found that hand-skimmed milk and flax seed gruel compared favorably with whole milk when fed with grain and clover hay to calves from 33 to 55 days old. Curtiss²⁵ later supplemented separator milk with oil meal, ground oats, and corn meal, and the results obtained indicated that corn meal ranked highest and oil meal lowest from the standpoint of gains. Grain and clover hay were fed in addition.

Plumb¹⁷⁵ compared hand skim milk with separator skim milk and found the former more efficient for calf feeding, due to its higher fat content. Lindsey¹⁰⁹ fed skim milk supplemented with corn meal, Buffalo gluten feed, and middlings, and stated that the addition of linseed meal or cod liver oil to the ration did not improve it. A year later he¹¹⁰ tried oleomargarine, cottonseed oil, corn oil, and brown sugar, and although the gains were slightly larger, the difference was not sufficient to compensate for the increased expense.

Rations of skim milk and oatmeal, and skim milk

and corn meal and flaxseed (9 to 1) gave better results than skim milk and new process oil meal, when fed by Curtiss.²⁶ Calves made satisfactory gains for Haecker⁶⁷ when fed skim milk supplemented with oats and flaxmeal, oats and flaxseed, oats and flaxseed meal, oats and bran, corn meal and bran, and corn meal. No particular difference was observed between the various grain mixtures.

²⁷ Curtiss, summarizing the results of several feeding trials, states that ground oats, and corn meal are better than oil meal for supplementing skim milk.

A variety of substances were tried out by Linfield¹¹³ of the Utah Experiment Station, and he reports no particular difference in the efficiency of wheat and bran, barley and bran, barley, peas and bran, corn and bran, and corn alone, in supplementing skim milk. All gave satisfactory gains.

To replace the fat in skim milk, Morse¹⁴⁵ used a mixture of ground flaxseed cooked in water, and later found that middlings satisfactorily replaced the flaxseed and cost less.

Cottrell and Otis²² fed skim milk and kafir corn meal, skim milk with Blatchford's calf meal gruel and kafir corn meal, skim milk with flaxseed meal jelly and kafir corn meal, and concluded that expensive feeds used with skim milk were not profitable.

²⁹ Two trials made by Dean to compare a mixture of

ground oats and bran fed dry, with Bibby's cream equivalent, a commercial product, led to the conclusion that bran and oats fed dry as soon as the calf will eat them are better and cheaper substitutes for cream than Bibby's cream equivalent. A later test³⁰ was made to compare bran, oats and oil cake with bran and Blatchford's calf meal. The calves gained more on bran, oats and oil meal than on bran and Blatchford's calf meal when fed with skim milk, but without skim milk the calf meal showed better gains. However, the results were not nearly so good as when skim milk was used with either combination. The author concludes that thrifty calves may be reared on skim milk with bran, ground oats and a little oil cake or linseed meal after getting a start of about three weeks on whole milk, but it is difficult to rear thrifty calves without the aid of skim milk.

Haecker⁶⁸ compared a group of calves which had sucked their dams with another group which had been fed whole milk ten days and then changed to skim milk supplemented with ground corn and oats, and found both lots the same at seven months.

Cotton seed meal, wheat bran, and cotton seed hulls were used to supplement skim milk by Moore.¹⁴⁴ Whole oats proved a satisfactory substitute for the fat in milk when tried by French.⁵¹ Haecker⁶⁹ obtained satisfactory results with linseed meal and corn germ oil meal fed in

conjunction with skim milk, but reports that corn oil is too expensive and difficult to handle in practical feeding operations.

Some extensive experiments were conducted by Otis¹⁶⁸ to test various methods of calf feeding. A seven months' trial showed that calves fed skim milk supplemented with grain made better and more economical gains than those receiving whole milk or running with their dams. A test of the addition of flaxseed meal, Blatchford's meal, or dried blood meal to the grain ration revealed the fact that shelled corn and ground kafir corn alone gave just as satisfactory and more economical gains than the more diversified rations. The conclusion was that excellent gains can be made from the use of feeds grown on the farm as supplements for skim milk.

Fain and Jarnagin⁴² fed corn alone and various mixtures of corn and bran and concluded that no advantage was secured from adding bran to a ration of shelled corn to supplement skim milk. On account of its laxative effect, black-strap molasses was found to be unsatisfactory as a skim milk supplement by Woodward and Lee.²¹⁶

Successful trials at various experiment stations led to a general recommendation of the use of skim milk with a supplementary grain mixture for rearing calves. Norton¹⁵⁰ outlined such a system for Michigan farmers, and Otis¹⁶⁹ of Wisconsin recommended the use of skim milk, butter milk, and whey, plus a good grain ration.

Hooper⁸⁶ concluded from his work that it seems unnecessary to use high priced whole milk or to purchase expensive oil bearing seeds such as flax seed, to supplement skim milk for calves that are two months old. He advocated the use of skim milk freely, supplementing it with some grain as the calf attains the age of six weeks to two months and begins to eat feed.

Woll and Voorhies²¹² state that the results of five feeding trials with dairy calves show that vigorous, thrifty calves, of very satisfactory body weights, can be readily raised on separator skim milk, grain feeds and hay; and that it is only necessary, as a rule, to feed whole milk during the first two weeks of the calf's life. They also tested the efficiency of linseed meal in the grain ration for dairy calves and concluded that whatever advantage may be derived from its inclusion will come from increasing somewhat the palatability of the feed and improving slightly the appearance of the calves, and not from any superior nutritive effect of the meal. This latter discovery is interesting, as the great majority of early feeders looked upon flaxseed or linseed meal as an indispensable part of all calf rations. Beet pulp or cocoanut meal fed with barley formed a successful grain supplement for skim milk.

⁵
In Canada, Archibald successfully used a home-mixed calf meal composed of two parts finely ground oats, four parts finely ground corn, and one part of ground flax

seed, fed in conjunction with skim milk.

The feeding of skim milk, with a suitable grain supplement to replace the butter fat, is now so generally practiced by dairymen and farmers, that its success is no longer open to question. The practice is recommended wherever skim milk is available. Directions for its use and formulae for grain mixtures to be fed along with the milk are set forth by Eekles,⁴⁰ Reed,¹⁸⁰ Woodward,²¹⁵ Hulce and Nevens,⁹¹ Hayden,⁷⁹ Brainerd and Davis,¹⁵ and a number of other authorities on dairy feeding.

All standard texts on the feeding of animals include directions for skim milk feeding together with recommendations of substitutes for the fat. Henry and Morrison⁸² preface a discussion of the practice of skim milk for calf feeding with the following: "The fat of milk is so valuable that but few dairy calves are now reared on whole milk when skim milk is available. Those prejudiced against the rearing of calves on skim milk by the sight of unthrifty, undersized skim-milk-fed specimens should know that such results are not due to the removal of the fat from the milk on which they were fed, but to the ignorance or carelessness of the feeder. Careful dairymen have abundantly demonstrated that skim milk calves, properly fed, develop into as good cows as those fed whole milk until weaning time." Writing of supplements they state that while various fats

and oils may be used to supplement skim milk, the cereal grains, rich in carbohydrates, are cheaper supplements than the oils available for calf feeding.

According to Jordan,⁹⁹ the exclusive feeding of skim milk for any length of time is not to be recommended. After the fat is removed from the milk the non-nitrogenous compounds are probably not present in sufficient proportion to protect the protein from waste as fuel. No feeding stuff appears to be a more efficient amendment of skim milk for the earliest feeding than flaxseed meal cooked into a porridge. Oil meal may be used in its stead but it is less desirable at first.

Woll²¹¹ gives a long list of grain feeds to be fed in connection with skim milk. These include corn meal; whole oats and bran; whole oats and corn chop; ground barley with bran or shelled corn; shelled corn and ground kafir corn or sorghum; whole oats, ground barley, and bran; corn meal, oatmeal, linseed meal, blood meal, and bone meal; whole oats, bran, corn meal, and linseed meal. This gives the feeder a wide scope in selecting his grain mixture.

Washburn²⁰¹ says that the quantity of skim milk fed per day should not be greater than would readily be consumed if the fat had been left in it, but the deficiency should be made up by substituting grain. He adds that the grain fed to a young calf should consist of a fine soft

meal, such as shorts, but when four weeks old the grain should have the same ingredients which would ordinarily be fed to dairy cows.

It is evident from the literature cited that the feeding of skim milk to calves has passed beyond the experimental stage, and the question of a suitable supplement has been definitely established, as the use of ordinary farm-grown grain mixtures has given entire satisfaction. The abandonment of the use of high priced oils and gruels and porridges, which demand laboratory conditions for their proper preparation, and the adoption of simple grain mixtures; together with the wide publicity given to the success secured in growing calves successfully on skim milk with grain supplements, have led to the inauguration of this system wherever skim milk is available.

The Use of Milk Substitutes in Calf Feeding.

The growth and development of cities and manufacturing centers, and congregation there of large numbers of people, has given rise to an increasing demand for whole milk. When the market is calling for milk and offering a fair price, there is a strong temptation for the dairyman to discontinue raising calves, or to seek a substitute for the milk on which the calves can be grown. Of these two practices, the latter is much to be preferred. Dairy heifers must be raised if herd improvement is to be continued and diseases kept under control. The food crisis has increased the difficulty and made more urgent the demand for whole milk substitutes, for milk prices have advanced; and in addition, there has been much agitation for a greater use of skim milk for human food.

Investigators are attacking the problem, and much experimental work has already been done in an endeavor to find a satisfactory substitute for whole milk for calf raising. Commercial firms are not overlooking this opportunity, and have flooded the market with calf meals in endless array, and elaborate claims are put forth as to the virtues of their products for feeding young calves.

The need for something to replace whole milk for raising calves was felt a score of years ago, and about that time Crawford²⁴ recommended a mixture of oil cake and oat meal, cooked and mixed with hay tea and a little milk as a milk substitute. Somerville¹⁹¹ suggested as a satisfactory feed for young calves, flour, one part; ground flaxseed, two parts; ground linseed cake, three parts. Two and one-half pounds of this mixture was considered a day's allowance for a calf, and the directions are to scald it with boiling water and then add sufficient water to make two gallons. This should be made to take the place of new milk after the first fortnight.

Hayward⁸⁰ undertook the first experiments with milk substitutes in this country. He criticised the calf meals then on the market by saying that they had not proven a success as complete milk substitutes. Hay tea was condemned because of the difficulty involved in its preparation and its failure when fed to young calves. He adopted as the basis of his early work an English formula, similar to the one mentioned above. In his preliminary work various combinations of flour, flaxseed meal, linseed meal, sugar, glucose, cocoanut meal, dried blood, fenugreek, and fennel-seed were tried. The following mixture was finally made up and proved satisfactory:

Wheat flour	30 lbs.
Cocoanut meal	25 "
Nutrium	20 "
Linseed meal	10 "
Dried blood	2 "

One pound of the mixed meal was added to six pounds of hot water and fed when it had cooled sufficiently.

Another mixture tried out included some corn meal and sifted ground oats in addition to the ingredients contained in the first.

The nutrium contained in this mixture is a soluble skim milk powder, and the author writes that there is little doubt that whatever success the calf meals experimented with attained was due largely, if not entirely, to the nutrium.

While he concluded that the trial was a complete success, part of his summary is that the calf meal is not as satisfactory a food as whole milk for very young calves and that for the first few weeks on this ration the calf does not have the vigor or power of resistance that it would have if fed upon its natural food.

²⁸Dean of Ontario reports the use of a decoction of cocoa shells, made by boiling one-fourth pound shells in two gallons of water, as a milk substitute; but in his conclusions states that there is probably no substitute which

will entirely take the place of milk for young stock.

A comparison of Blatchford's calf meal, a commercial product, with home-mixed Hayward's calf meal was made by Lindsey.¹¹¹ The meals were fed in water. Whole milk was given for nine to fourteen days and its use discontinued at three weeks. Three quarts of skim milk were then fed daily in addition to the calf meal until the calves were four to five weeks old. The conclusion was that Blatchford's calf meal was not as satisfactory as the home-made product during the first three months of the calf's life. Both meals were very successfully used in conjunction with skim milk.

Otis¹⁶⁸ experienced difficulty in replacing milk with whey. He then experimented with hay tea, the preparation of which proved to be a tedious process, and the indifferent results obtained did not warrant its use as a milk substitute.

According to Michels,¹⁴⁰ a feed that could take the place of milk for young calves must be very palatable and digestible, rich in muscle and bone-forming materials, and practically free from crude fiber. Cooked rolled oats seemed to meet these requirements when prepared by adding boiling water to them at the rate of one gallon of water to 12 ounces of rolled oats. He fed ten pounds of whole milk daily the first week; the second week the allowance was 8 lbs. whole milk and 4 oz. rolled oats; third week, 6 lbs. whole milk and 8 oz. rolled oats; fourth week, 4 lbs. whole

milk and 12 oz. rolled oats; next five weeks, 2 lbs. whole milk and 12 oz. rolled oats; and from the tenth week on, 12 oz. rolled oats. A grain mixture of corn meal, linseed meal and wheat bran was gradually added from the fifth week on. Nine calves were fed and daily gains of from 1.0 to 1.3 lbs. were realized. Results obtained warranted the recommendation of the feeding of cooked rolled oats to calves where no skimmed milk or an insufficient quantity for calf rearing is available.

Woodward²¹⁶ reports the use of a milk substitute in Louisiana. Calves were kept on their dams two days and then fed whole milk about five days. The milk was then reduced until the calf received two pints per day, which amount was fed until six weeks of age. While the milk was being reduced, bean soup, shorts, blood meal, and sometimes cottonseed meal were added to the calf's daily ration until at ten days it was receiving soup from 4 oz. navy beans, 3 oz. shorts, 1 oz. blood meal, and probably 3 oz. cotton seed meal. Alfalfa hay was fed ad libitum. This "soup" is prepared according to the following directions: parboil the beans in soda, then drain off the water and boil again until soft. Squeeze through a collender and add salt until brackish. Stir in shorts, blood meal and cottonseed meal and add lukewarm water until each calf receives about three quarts of the mixture.

Wing, Savage, and Tailby took up the problem of milk substitutes, and their first work was a trial of two commercial calf meals, Lactina Suisse, and Schumacher Calf Meal. These were compared with skim milk for replacing whole milk. Lot A, fed on skim milk, gained on the average 1.76 lbs. per day at a cost of 4.8 cts. per pound. Lot B, 6 calves, received Schumacher Calf Meal, fed according to directions, and gained 1.25 lbs. a day on the average, at a cost of 8.1 cts. a pound. Lot C, 5 calves, fed Lactina Suisse according to directions, gained 0.7 lb. a day on the average, at a cost of 11.6 cts. a pound. All lots were fed a dry grain mixture of corn, oats, bran and oil meal, which they ate at will, and in addition hay was kept before the calves at all times. The trial lasted 120 days. In commenting on the Schumacher Calf Meal, the authors state that some trouble was experienced in getting the calves to take the meal gruel readily and the amounts called for by the directions seemed a little large in some cases and had to be cut down. One calf did not do well on the meal alone and some skimmed milk was added to its ration. The conclusions were that Schumacher Calf Meal did not appear to be a complete substitute for skimmed milk; yet the gains from its use were good. In case of the Lactine Suisse, the gains per day became greater as the calves grew older, but this food did not seem to be nearly equal to skimmed milk or Schumacher Calf Meal at any

corresponding periods of age.

The following year another trial was made with four groups of calves. Lot D, 7 calves, fed skimmed milk, gained an average of 1.53 lbs. daily at a cost of 4.8 cts. a pound. Lot E, 6 calves, which received skimmed milk powder, one pound of which was dissolved in nine pounds of water, made average daily gains of 1.23 lbs. at a cost of 6.4 cts. a pound. Lot F, 4 calves, fed Schumacher Calf Meal according to directions, gained on the average 1.10 lbs. daily at a cost of 9 cts. a pound. Lot G, 4 calves, which received Blatchford's Calf Meal according to directions, made daily gains of 0.87 lb. on the average, costing 13.4 cts. a pound. Grain and hay were fed as in the previous trial, and the duration of the test was 150 days.

Results led to the conclusions that skimmed milk gave the best results as a substitute for whole milk, yet the other foods, skimmed milk powder, Schumacher Calf Meal and Blatchford's Calf Meal, gave fair results. The dried skimmed milk powder was worth the most as a substitute for skimmed milk.

Summarizing the results of two years' work, the authors ranked skimmed milk, hay, and grain as the best substitute for whole milk, with third grade dried skimmed milk powder second. Schumacher Calf Meal seemed to be the best commercial substitute, in the nature of grain, for

skimmed milk. Blatchford's Calf Meal and Lactina Suisse were considered too expensive to use except in extraordinary circumstances.

In a later publication, the authors²⁰⁹ called attention to the later development of these experimental animals, and part of their summary reads as follows: "The writers do not wish to put themselves on record as maintaining that it does not matter how calves are fed, that the results when they become two or three years old will be the same in any case. Rather, it is intended to show that the heredity of the animal is of more consequence than any moderate influence in the care or feeding for a short time at the beginning of the development of the individual. If the calf is not stunted permanently by continuing poor feed for too long a time, the lack of thrift which might result from using a substitute for milk from the time the calf is ten days or two weeks old until he is on hay and grain entirely, may be overcome in the later development of the animal if the dry food given from the time he is five months of age is proper and sufficient in amount."

It is interesting here to note that all estimates and calculations of growth and increase in size are on a basis of increase in weight and gain in pounds.

¹²Beach approached the problem of milk substitutes from a different angle, considering the factor of the

digestibility of calf meals when used to substitute skim milk. He fed two lots of four calves each, and each lot received equal amounts of hay and grain. The following table furnishes an interesting comparison:

	Whole Milk lbs.	Skim Milk lbs.	Calf Meal lbs.	Gain in Weight lbs.
Lot 1, Milk	764	3412		364
Lot 2, Calf meal	600	424	240	188

The estimated dry matter (exclusive of hay and bran) required for one pound gain was 1.09 lbs. for Lot 1, and 1.79 lbs. for Lot 2. The smaller gains made by Lot 2 are attributed to the inability of the calves to digest and assimilate the calf meals. For the young animal a satisfactory substitute for milk must be one which is easily digested and assimilated.

Lindsey¹¹² experimented with various proprietary calf meals and a number which he prepared, the composition of the latter being somewhat similar throughout, yet varied enough to enable the exercise of a choice in selecting one for use. They are listed below:

Lindsey's Calf Meal I.

10 lbs. fine corn meal
10 lbs. flour middlings
15 lbs. flaxseed meal
10 lbs. cheap flour
5 lbs. glucose sugar
1 lb. salt.

• Lindsey's Calf Meal II.

25 lbs. ground oat flakes
15 lbs. flaxseed meal
8 lbs. cheap flour
2 lbs. glucose sugar
1 lb. salt.

Lindsey's Calf Meal III.

8 lbs. fine corn meal
10 lbs. flour middlings
14½ lbs. flaxseed meal
10 lbs. cheap flour
7 lbs. glucose sugar
½ lb. salt.

Lindsey's Calf Meal IV.

10 lbs. Fine corn meal
10 lbs. flour middlings
14½ lbs. flaxseed meal
15 lbs. cheap flour
½ lb. salt.

Lindsey's Calf Meal V.

11 lbs. fine corn meal
5 lbs. flour middlings
10 lbs. flaxseed meal
22 lbs. ground oat flakes.
1½ lbs. prepared blood flour
½ lb. salt.

Lindsey's Calf Meal VI.

35 lbs. ground oat flakes
1½ lbs. prepared blood flour
12½ lbs. barley malt
½ lb. bicarbonate soda
½ lb. salt

The following table summarizes the results of various trials:

Kind of ration	No. Calves	Days in Trial	Daily Gains lbs.	Cost of food per lb. gain. cts.
Skim milk in large supply, ordinary grains and hay,	10	235	1.22	7.7
Skim milk and Hayward's Calf Meal,	2	173	1.23	9.6
Skim milk and Schumacher's Calf Meal,	3	150	1.00	8.2
Skim milk and Blatchford's Calf Meal,	1		1.15	
Whole and skim milk and Bibby's Cream Equivalent,	3	148	1.21	7.5
Whole and skim milk and Lindsey's meal I.,	2	147	0.97	10.4
Whole and skim milk and Lindsey's meal II.,	3	183	1.04	7.6
Whole and skim milk and Lindsey's meal III.,	1	148	1.70	6.1
Whole and skim milk and Lindsey's meal IV.,	1	148	1.50	6.5
Whole and skim milk and Lindsey's meal V.,	4	164	1.25	7.6
Whole and skim milk and Lindsey's meal VI.,	3	157	1.35	7.6

While this presents quite an array of figures, it will be observed at once that none of the trials embrace more than a very limited number of animals, and because indivi-

duality is such a great factor in animal feeding, the stress which should be laid on such a limited trial should not be too great.

The author writes that these results indicate that calf meals may be purchased or prepared that will take the place of a considerable amount of whole or skim milk and not interfere with the normal growth of the calf. It is doubtful, however, if one will be able to find any article or combination of articles that will completely take the place of milk during the first two or three months of the calf's life. He did not think it advisable to attempt to rear the calves during the first four months without the use daily of three to five quarts of skim milk. A too early attempt to accustom the calf to an exclusive diet of calf meal is likely to produce digestive disturbances that may affect the health of the animal in after life.

In commenting on calf meals Lindsey says that many of the meals are made, so far as the relative proportions of the several ingredients are concerned, to imitate dry skim milk. He refrained from making a mixture with over twenty per cent protein, because the protein of milk exists in solution as casein and lactalbumin--easily digested and assimilated forms of nitrogen--while the protein in the different grains is in forms not so easily utilized by the young animal. In preparing a calf meal the object should be to use only those ingredients that are easily and highly

digestible, and at the same time are not too expensive. Among such feeds may be mentioned finely ground corn meal, flour middlings, ground rice, wheat flour, oat flakes, barley malt, cocoanut meal and flaxseed meal. Dry skim milk is a valuable substance, but its cost is likely to prevent its use.

In conclusion he states that calf meal will serve as a partial milk substitute, but if skim milk can be had at not over two-thirds to three-fourths of a cent a quart, it is to be preferred to calf meal at three cents a pound.

⁹⁰ Hubbard fed sixteen calves in four lots in order to test a commercial calf meal. Lot I. received whole milk; Lot II. skim milk and a mixture of oats, corn and ground flaxseed; Lot III. calf meal and water with no milk; and Lot IV. calf meal and skim milk. Calves fed the grain mixture with skim milk averaged 1.61 lbs. gain a day at a cost of 2.84 cts. a pound; while the lot fed the calf meal and water gained 0.87 lb. daily at a cost of 12.33 cts. a pound. The skim milk and calf meal group made gains equal to those on the grain mixture, but at double the cost.

Three groups of calves fed experimentally by Hutton⁹⁵ received whole milk for the first two weeks. Lot 1 then received linseed oil cake; Lot 2, Blatchford's calf meal; and Lot 3, skim milk. All were fed a dry grain

mixture and roughage of clover hay, mangels and silage. The skim milk calves made greatest gains at lowest cost; while those fed Blatchford's calf meal made the least gains at the highest cost a pound.

Giuliani⁵⁷ tried replacing milk with Blatchford's Calf Meal by gradual substitution and found that the more milk he replaced, the greater the loss of appetite shown by the animals. The appetite of the calves decreased so much that it was necessary to change the feeding after a few days to prevent death. The results of the experiment led to the conclusion that Blatchford's Calf Meal cannot entirely replace milk, either from a physiological or an economical point of view. Physiologically it can be used with success under some circumstances as a partial substitute for milk.

Washington Experiment Station²⁰² reports that in a ninety-day test of milk substitutes, skim milk gave the best results; but other foods, such as Blatchford's Calf Meal and a home grain mixture, together with a limited use of skim milk, gave fair results. Grain mixtures fed dry rather than mixed with milk gave best results.

For the purpose of furnishing dairymen with practical and reliable information as to the proper preparation and use of rations for calf feeding when whole milk is not available, Hunziker and Caldwell⁹³ published

the results of extensive experiments comparing skim milk, a home-mixed calf meal, and Blatchford's Calf Meal. The calves were grouped in three lots of ten calves each, and fed the following rations:

Lot I., whole milk, skim milk, ground corn and oats as a dry mash, alfalfa hay and corn silage.

Lot II., whole milk, home-mixed calf meal (containing hominy feed, linseed meal, red dog flour and dried blood, equal parts by weight), ground corn and oats as a dry mash, alfalfa hay and corn silage.

Lot III., whole milk, Blatchford's calf meal, ground corn and oats as a dry mash, alfalfa hay and corn silage.

All calves remained with their dams for a period of four to five days, at the end of which time they were placed on bucket feeding. The skim milk calves received whole milk until they were three weeks of age, but during the second and third weeks, skim milk was gradually substituted, placing the calf on a full ration of this material at three weeks of age. Lot II., at seven days of age, received a small amount of home-mixed calf meal mixed with the milk. This material was gradually increased and mixed with water in the proportion of one part of meal to seven parts of water. As this mixture was increased, the amount of whole milk was decreased so that by the time the calves

were five weeks of age, they were scheduled to receive a full ration of calf meal, which usually consisted of eighteen to twenty ounces per head per day. This method of feeding was continued until the calves were six months old, at which time they were receiving twenty-four ounces a head daily. A small amount of Blatchford's Calf Meal was placed in the milk fed to calves in Lot III. during the second week. This amount was gradually increased and mixed with water according to directions. At five weeks of age, all calves in this lot were scheduled to be on a full ration of calf meal consisting of seventeen ounces a day. This amount was gradually increased until the calves were six months of age, at which time they were receiving twenty-two ounces a head daily.

Using increases in both weight and height as indexes of growth, the following table furnishes a striking contrast:

	Average daily gain, Pounds	Average monthly growth, Inches	Cost per lb. Gain, Cents
Lot I.	1.21	2.08	5.7
Lot II.	0.95	1.54	7.4
Lot III.	0.73	1.46	13.1

Conclusions drawn by the authors are that the use of skim milk as a feed for young calves should be encouraged

unless its market value is above thirty cents per hundred pounds, and so long as skim milk is available as a feed for live stock, milk substitutes for dairy calves are of comparatively limited value.

Where whole milk is sold, the use of a home-mixed calf meal is advisable although the calf so produced will not be as well developed at six months of age as if fed milk during its early growing period.

The results, from the standpoint of gain in weight and growth in height, produced by feeding Blatchford's Calf Meal do not warrant its recommendation as an absolute milk substitute for the growing of dairy calves.

Two of the calves in the group fed Blatchford's Calf Meal died before the completion of the test, and in general the experience seems to coincide with results secured by other investigators cited before.

Hunziker⁹⁴ continued the work at Purdue, and used five different home mixtures in order to test the relative efficiency of animal and vegetable proteins in calf meals. The five rations were made up as follows: No. 1, hominy feed, linseed meal, wheat middlings and blood flour, mixed equal parts by weight; No. 2, soybean meal, cottonseed meal, wheat middlings and linseed meal, mixed equal parts by weight; No. 3, blood flour, hominy feed and wheat bran, mixed equal parts by weight; No. 4, black albumen, two

parts by weight, wheat middlings, four parts by weight, soybean meal, five parts by weight, and linseed meal, five parts by weight; No. 5, same as meal No. 1 except that skim milk was fed in place of whole milk and only a limited supply fed.

It required 3.63 lbs. of whole milk a head daily, in addition to meal No. 1 to produce a gain of one pound per day. Meal No. 2 (vegetable protein) required 2.71 pounds of whole milk in addition to the meal to yield a body gain of 0.73 pound daily. Meal No. 3 (animal protein) yielded a body gain of 0.8 pound daily through the use of 1.54 pounds of milk in addition to calf meal fed. Meal No. 4 produced a fair gain in body weight but required an excess of whole milk due to the extreme laxativeness of certain ingredients in the meal. Meal No. 5 produced a daily gain of 0.91 pound and required but 0.35 pound of whole milk in connection with 3.25 pounds of skim milk. The use of 3.25 pounds of skim milk took the place of an equal amount of whole milk with a loss of but 0.11 pound daily gain.

An effort was next made to simplify the grain mixture fed as a calf meal, and Woodbury²¹⁴ reported that after numerous trials the following was selected as the one giving the best results: ground corn, eight parts; oil meal, one part; dried blood, one part. One and one-half per cent of steamed ground bone meal was added to supply the

deficiency of ash. The results of feeding experiments demonstrated that this mixture can be fed successfully to very young calves and produces normal growth.

Wing²¹⁰ of Missouri reviewed the work done with milk substitutes and undertook an experiment to determine the possibility of using powdered skim milk for feeding young dairy calves, and the economy of such a practice. He fed three lots of three calves each according to the following plan:

Lot I. received skim milk, hay and grain.

Lot II. received powdered skim milk in place of ordinary skim milk; the powder to be fed in the dry form mixed with ground corn, equal parts by weight. The calves were to receive this ration until they were 120 days of age and then placed on a ration of grain and hay.

Lot III. fed skim milk powder and ground corn until 90 days of age, and then placed on a grain and hay ration.

The calves in Lot I. made an average daily gain of 1.2 lbs. for the first 150 days of their lives. Lot II. made an average daily gain of 0.86 lb. for 180 days; and Lot III., 0.92 lb. for 180 days.

In conclusion the author states that the best substitute for whole milk, in the raising of calves, is a ration of skim milk, hay and grain. Many attempts have been made to find a substitute for milk in calf raising

but the results in most cases have not been satisfactory. Good, strong, and healthy calves can be raised on dried skim milk with results which compare favorably with those obtained from feeding skim milk in the ordinary form. The feeding of powdered skim milk to the age of ninety days gave equally as satisfactory results as when continued to the age of 120 days.

Analyses of proprietary calf meals are supplied by the various experiment stations through their feed inspection bulletins, and it is interesting to note the array of articles which are incorporated into these commercial mixtures. Most of the ingredients are present because of their food value, but the practice seems to be to add thereto some nonessentials, either to give the feed a pleasant aroma, or to endeavor to tempt the appetite. The following list of articles was compiled from the contents of about half a dozen calf meals as determined by analysis at the Indiana Experiment Station:¹⁷⁶

Fenugreek	Cocoanut meal
Anise	Corn feed meal
Cottonseed meal	Oat meal
Locust bean meal	Wheat Middlings
Flaxseed meal	Meat meal
Linseed meal	Fish meal
Wheat flour	Bone meal
Blood flour	Limestone grit

Barley meal	Hominy feed
Bean meal	Wheat starch
Pea meal	Carob beans
Dried milk	Lentil meal
Rice polish	Ginger
Cocoa shells	Oxide of iron
Salt	Corn starch
Sugar	Red dog flour
Malt flour	Gluten feed
Rye middlings	Calcium hydroxide
Milk casein	Toasted corn flake
	by-product.

Current Opinion Regarding the Use of Milk Substitutes.

The foregoing concludes the review of the experimental work which has been reported on the problem of milk substitutes for calf rearing, and while some of the trials have been reported as highly successful, the degree of success in the use of calf meals, both commercial and home-mixed, does not seem to have been sufficient to warrant a general recommendation of their use as entire substitutes for milk. Authorities on feeding are skeptical as to the ability of the ordinary feeder to accomplish satisfactory results by the use of these meals. Accordingly, entire approval is usually withheld, and only limited recognition of their value is acknowledged. Some of the following quotations from texts on feeding suggest this attitude.

Henry and Morrison⁸² make no recommendation of the use of milk substitutes, but confine themselves to a review of experimental work done and results obtained. They write of proprietary calf meals as follows: "There are on the market several calf meals, which are more or less complex mixtures of such feeds as linseed meal or flaxseed meal, ground cereals, and wheat by-products, with or without dried milk, casein, and mild drugs. These meals are fairly satisfactory substitutes for skim milk, but give no better returns than home-mixed meals that are much less expensive."

The following is quoted from Kellner:¹⁰⁷ "An excellent substitute for whole milk is found in Liebig's recipe, which is also suitable for those calves that cannot digest the mother's milk. Liebig's directions for preparing his milk substitute are as follows: For each calf take $3\frac{1}{2}$ quarts of milk, $3\frac{1}{2}$ quarts of water, 10 oz. of wheat flour, 10 oz. of ground malt, and $\frac{1}{4}$ oz. potassium bicarbonate. The flour is boiled with the water and half of the milk to form a porridge, and when this is cold the other half of the milk, in which the potassium bicarbonate is dissolved, is added, and the ground malt stirred in. The mixture is then allowed to stand for half an hour in a warm place, then once more boiled and sieved through muslin."

Washburn²⁰¹ writes: "For many years various concoctions have been tried and a few recommended as substitutes for milk in calf feeding. To make a long story short, the results of the many trials is that calves can be successfully reared upon a very small quantity of milk used in conjunction with an adequate amount of mixed grains, but that milk in some amount is practically essential."

The same skepticism is quite generally voiced by the best dairy authorities in their advice to feeders.

Eckles,⁴⁰ in writing of localities where whole milk is sold, states that under these conditions the plan most commonly followed is to use the least possible amount of

milk, making use of grain or some other substitute as far as possible. Calf meals prepared and sold under various names and designed to take the place of milk are frequently used. Some of these, especially those that contain a portion of dried skim milk, are reasonably successful, although equally good results can usually be obtained by the mixture of grain prepared by the feeder. The raising of calves in a satisfactory manner under these conditions is much more difficult than raising them where skim milk is at hand.

The following is quoted from Hulce and Nevens,⁹¹ on home-mixed milk supplements: "It is necessary, in using a milk supplement other than skim milk, to feed a considerable amount of whole milk. The amount of milk required is about a pound daily for every eight pounds of live weight, until the animal is four or five weeks old. At that age a milk supplement may be substituted gradually for the milk. As a rule, the use of milk should be continued until the calf is at least sixty days of age. The calf meals sold on the market are useful as supplements to whole milk, but as yet they have not been so compounded that they will successfully replace whole milk before the calf is several weeks old. Calf meals alone, or calf meals, grain, and hay do not form a complete ration for the young calf, since they do not supply the necessary nutrients in a form readily digested and assimilated. To produce satisfactory growth

of the young calf when fed a calf meal, it is best to use the meal as a supplement to milk rather than as a complete substitute for it. It is doubtful if, under average conditions, good gains will be made unless some milk is fed until the calf is about sixty days of age. In most cases the manufacturers of calf meals claim more than is warranted for their products as substitutes for milk."

⁷⁹ Hayden says that if some feed can be found which will successfully take the place of milk from the time the calf is eight to ten days old, and which is materially cheaper than milk, a great service will be rendered to the dairy industry. Some Experiment Stations and a good many other persons have experimented along this line, but no really satisfactory feed has yet been discovered. There are feeds on the market that are fairly satisfactory after the calf has passed the greater part of the milk period, but they are usually good supplements rather than substitutes. The best of these contain milk powder which is expensive.

The following comment on milk substitutes is made by Brainerd and Davis:¹⁵ "While it is probably not practicable to take calves two days old from the cows and raise them entirely without milk, some skillful feeders have been able to approximate these conditions. It is hardly safe, as a rule, even with the most vigorous calves, to attempt to put them on milk substitutes alone within one week

after birth; and with calves below the normal in vigor, some milk for two weeks or more may be necessary to raise them. In supplying a substitute for milk an attempt is usually made to use a liquid the composition of which resembles milk as much as possible.

"All milk substitutes lack a great deal of being as satisfactory as either whole or skim milk, and milk has to be very high in price to justify the use of milk substitutes during the first two weeks of the calf's life.

. 215
Woodward says, "It has been found possible by careful handling to raise calves without milk after three or four weeks old. Such calves are usually badly stunted but may recover from the effects to some extent if well fed in later life. It is not practical to raise calves in this way."

180
Where whole milk is sold, Reed recommends that the calves be fed the minimum quantity of milk, getting the animals to eat grain, or gruels made of grain, as early as possible. He says there are a great many milk substitutes advertised on the market, but these are usually expensive, and for the best results some milk should be fed with them.

213
Woll and Voorhees write as follows: "When skim milk cannot be obtained, it will be necessary to feed whole milk until the calves are sufficiently strong and thrifty

to do well on a gruel of ground grain and mill feeds, at about three or four weeks old. It is a difficult undertaking to raise very young calves successfully without milk and calls for constant care and watchfulness on the part of the feeder. Commercial calf feeds will give satisfactory results in some cases, but are relatively expensive."

The following is copied from the Journal of the Board of Agriculture¹⁰⁰ of London: "Unfortunately, both experience and experiments show that to eliminate milk altogether in rearing is extremely undesirable, if not practically impossible. Much, however, may be done with a little milk judiciously supplemented with other foods. These foods should be selected to furnish as nearly as possible an equivalent for the milk when the use of the latter is entirely suspended. The question of indigestible matter, and that of choosing meals that will agree with the calf, constitute the practical difficulties."

Raising Calves by the Use of a Minimum Amount of Milk.

Another system of calf raising suggests itself to the dairyman who sells whole milk. This method is in practical use on many farms, but very little information is published as to the system followed or the results obtained. It consists merely in feeding the calf just a sufficient quantity of milk to give it a satisfactory start in life, or to carry it to that stage of development where it is able to continue its uninterrupted growth on grain and hay.

⁵⁰
Fraser and Brand, of the Illinois Experiment Station, attempted a solution of this problem in a series of feeding experiments. An effort was made to give the animals only a small quantity of whole milk, and to feed them largely upon skim milk when but a few days old. In a preliminary trial with three calves, they were entirely cut off from milk at forty-two, forty-five, and forty-six days of age, but this method of handling resulted in digestive disturbances and the results were not satisfactory. However, it demonstrated in a very striking manner that the most important thing in raising calves is to give them a good start, and during the first two weeks of their lives they must be fed a reasonable amount of whole milk.

A second and a third tests were made with twelve and six animals, respectively, and the second lot of calves

was reared on amounts of milk varying from 540 to 638 pounds, which the authors conclude is ample to raise calves successfully.

Summarizing the results of all trials, they state that calves should be given a fairly good start on whole milk during the first three weeks, and that after this, whole milk may be successfully replaced with skim milk. The calves should be continued on twelve pounds of skim milk a day until they are about seven weeks old, and thereafter the amount may be rapidly reduced, so that by the time they are about eight weeks old, they will be receiving no milk at all. They add that there is a lack of sufficient data from which to draw absolute conclusions regarding the amount of milk required to raise a calf. Where it is possible, more milk than used in this experiment is recommended, as it is always best to keep a calf in a good growing condition from its birth to maturity.

At the Florida Experiment Station⁴⁵ three lots of calves were fed as follows: Lot I. calves were fed four quarts of whole milk daily; Lot II., four quarts of whole milk and twelve ounces oat meal; and Lot III., eight quarts of whole milk. Gains made by the first two lots were unsatisfactory and the quantity of milk fed was obviously insufficient.

The experiments reported in this thesis were

carried on with a view of securing more data and information on a system of calf feeding involving the use of a minimum amount of milk.

REVIEW OF LITERATURE -- PART TWO.

Growth.

The fundamental purpose in feeding young animals is to induce growth and development. In view of the recent advances which have been made in the science of nutrition, this thesis would be incomplete without some discussion and review of facts revealed and theories and hypotheses advanced by the numerous investigators in the field of nutrition. Some comment on growth and the factors aside from nutrition which influence it would not be amiss, as they demand consideration if the feeder is to fully understand his work.

This review is liberally interspersed with direct quotations, but it is obvious that the author's words usually express his thoughts and conclusions more clearly and concisely than could be done by one who reproduces them at second hand.

Definitions of the term "growth" are almost as numerous as are the men who have written on the subject, and while there is a general understanding of what is implied by the word in its ordinary sense, there is still

much quibbling as to its application in scientific work, due largely to the fact that different investigators have adopted various methods of measuring growth.

Mendel¹³⁸ gives expression to the uncertainty which clothes the use of the word, thus: "What is growth? One cannot penetrate far into the literature of the subject without meeting with a bewildering confusion in the significance of the term. The most general definition of growth is 'increase in volume' or 'increase in size' (Huxley). It has been pointed out, however, that increase in volume does not always serve as an index of organic growth; for the increase may merely be due to swelling. Sachs defined growth as an increase in volume accompanied by a change in form. No universally acceptable definition has been framed; nor is it likely that one can consider all of the manifold features of growth in a single category. What is needed today is less of theory and more of facts upon which to build a more substantial conception of growth and formulate its fixed characteristics in words."

We are not dealing with a mere increase in weight or size, but as the individual passes through the various stages of development from the time the egg is fertilized until maturity is attained, the physiological changes which it undergoes in reaching the size, form, and characteristics of the matured members of its species constitute growth.

148

Mumford states that from the fertilization of the egg until the full development of the mature individual, the animal increases in volume and changes in form, and this increase and change of form is called growth. The final size of an animal is determined by the rate of growth and the length of the growth period.

6

According to Armsby, growth may be characterized briefly as consisting in an increase of the structural elements of the body, chiefly by cell multiplication, resulting in a gain in size and weight.

Growth, as represented by increase in size or weight, may be brought about by multiplication of the cells, enlargement of the individual cells, or deposition of intercellular material. The first of these is without doubt the most potent.

How growth should be measured, and the establishment of some accurate criterion thereof, still remain unsettled. The lack of a common standard has led to some confusion which could be obviated by the establishment of uniformity in methods of weighing and measuring experimental animals. This would result in making work of different experimentalists comparable to a greater degree than at present. Some progress has been made by the establishment of growth curves. Periodic measurements of large numbers of individuals of various species have been compiled and

expressed in graphic form, and the use of such curves of normal growth is of value for comparative purposes. Individual variations are largely overcome by the employment of statistics from a large number of animals.

Nature of Growth - At the time of the fertilization of the egg, or union of the sperm and ovum, a powerful force is set in motion. This "growth stimulus" is generally believed to continue operative until it is spent by the organism in achieving its complete growth. Its action may be retarded by adverse conditions, but with favorable environment, its function is revived and growth often proceeds at an accelerated rate. The exact nature of this inherent growth impulse has not been determined, but its presence is no longer questioned, and its persistence has been repeatedly demonstrated by dogged efforts of animals to grow under most unfavorable circumstances.

In addition to this internal source of influence, growth receives an additional impetus from an external source, its main factor being the food supply. The two are closely involved and dependent on each other. Nutrition can only give the growth impulse full play, but neither can succeed without the other. The stimulus to grow must be suspended when adequate food is lacking, but on the other hand, no amount of food can force the animal

to grow beyond its predetermined size, and when its growth impulse is spent, heavy feeding cannot revive nor recreate it. Of the two factors, the growth impulse is independent of the will; whereas nutrition is under control.

¹¹⁴
Loeb, from his studies of the stimulation of growth, draws the following interesting conclusions: "In the body, cells may be at rest or growing, and we do not know whether the conditions which determine rest are identical with those determining rest in the egg. We know, however, that specific substances circulating in the blood can induce certain resting cells in the body to grow and that these substances differ apparently for different types of cells. It may be that in the body substances antagonistic to these may enforce the inactivity of the cells."

¹³⁸
Mendel writes that quite aside from the question as to what initiates growth, the capacity to grow--the "Wachstumsfähigkeit", or "Wachstumsmöglichkeit" as it has variously been termed--is commonly made a property of the cells of the organism; and that whatever may be the ultimate cause of growth, the capacity to grow is currently associated with a youthful character of the cells involved.

²³
Cramer concludes that the water content of different tissues varies with their rate of growth. It is

highest in rapidly growing tissues and lowest in slowly growing tissues. This means that rapidly growing cells have the property of building up protoplasm with relatively less of the complex organic substances, such as proteins, lipoids, etc., and relatively more water. This property is in itself an explanation of the biochemical mechanism of growth.

Weismann claimed immortality for all unicellular organisms, and Minot¹⁴¹ long ago voiced the theory that the growth and differentiation of the protoplasm of the cell are the cause of the loss of its power to grow. He adds that over ninety-eight per cent of the original growth power of the rabbit or of the chick has been lost at the time of birth or hatching, respectively, and the same thing is equally true of man. Growth of the germ up to the time of birth represents an increase of over five million per cent.

It would appear that the growth stimulus is more potent in the youthful cell, and with advancing age and development, as the cell structure becomes more complex and altered for specialization, the impulse dies down; at least, observation would lead to this belief. However, there is also the possibility that with advancing age, other inhibitory forces are set up which overcome and counteract the original power of growth.

Internal Secretions - Another factor, or factors, which enters into the problem of growth, and which has not as yet been brought under absolute control of the will, is that class of substances commonly known as "internal secretions." According to Howell,⁸⁹ the term is used to designate those secretions of glandular tissues which, instead of being carried off to the exterior by a duct, are eliminated in the blood or lymph. The organs which elaborate these secretions are usually referred to as the glands of internal secretion, but Schäfer¹⁸⁸ uses the name "endocrine organs"; while Mathews¹³⁷ elects to call them "cryptorrhetic organs". They are also popularly designated as the ductless glands.

The nomenclature of the products themselves is still a subject of controversy, and although the generally accepted term "hormone" has found wide use in physiological literature, some writers have felt that a more characteristic name should be adopted. Schäfer¹⁸⁸ says, "Since the most characteristic feature of the action of these substances is the resemblance to the action of drugs, I propose to employ for these specific substances the general title autacoid substances, or, simply autacoids. I would accordingly define an autacoid as a specific organic substance formed by the cells of one organ, and passed from them into the circulating fluid to produce effects upon other organs similar to those produced by drugs."

Among the internally secreting organs the thyroid, parathyroids, ovaries and testes, pancreas, hypophysis or pituitary body, and suprarenals are the most important. The thymus and pineal glands, although little is known of their functions, should be included in this list.

In dealing with the specific action of the products of these organs we are still treading to a great extent the uncertain ground of hypothesis. Their functions are so interwoven and the balance of the entire system of these interacting organs is so delicate, that experimental work yields results which do not always carry conviction. It cannot be said with absolute certainty just which of the glands influence growth, as the specific action of any one of them may be entirely dependent upon a sympathetic action of one or more of the others. The doubt which assails the most profound students of growth is expressed by Mendel¹³⁸ when he says, "It may be that the rythm of cell division and its attendant features, which some have identified as the detectable expression of the capacity to grow, is dependent upon the action of 'hormones', products of internal secretion and cellular metabolism. If this is true we shall have at our disposal some means of modifying the internal factors of growth. For the present we must content ourselves with the unsatisfying conclusion that to unravel the inner nature of

growth is to penetrate the secret of the distinguishing characteristics of living substance. Here hypotheses reign uncontrolled."

⁵⁸
Gley reviewed the investigational work and states that in spite of the vast amount of work on the subject that has been published in the past twenty-five years the quantity of exact knowledge is still disappointingly small. As a criticism of some of the methods employed he adds, "It could not be taken as proven that the substances found in the extracts made from the organs were actually present in those organs during life. These extracts were often highly toxic, yet it must not be rashly assumed that the toxicity was due to specific substances secreted by the organ. The toxicity here might depend upon many conditions and most of all upon the method by which the extract was prepared." This statement, if true, would tend to undermine those conclusions drawn from results obtained by the use of extracts of the glands.

It cannot be said with absolute certainty just which of these ductless glands influence the growth of the organism because of their interdependence and reciprocal influences. Mathews¹³⁷ says that the hypophysis, thyroids, sexual glands, adrenals and thymus are a closely related series of organs which mutually influence each other's growth. The thyroid and hypophysis stimulate the

chromaffine tissue, the latter inhibits the pancreas, ovaries and parathyroids; the latter inhibit, or are inhibited by, the thyroids and hypophysis. He adds that the body is an organic whole and these so-called cryptorrhetic organs, organs of internal secretion, are not unique, but the bones, muscles, skin, brain, and every part of the body are furnishing internal secretions necessary to the development and proper functioning of all the other organs of the body.

Kellicott¹⁰⁵ writes that it seems quite likely that in organisms in general the normal growth of each tissue or even each organ is controlled separately by a specific internal secretion, and these substances may regulate growth either through inhibition or acceleration, and the effect may be due either to the presence or withdrawal of the specific substance. To quote further from Mathews,¹³⁷ "We see in the internal secretions that every character in the body involves a large number of factors. The shape and size of the body; the coarseness of the hair; the persistence of the teeth; tendency toward fatness, may easily depend on the hypophysis, on the thyroid and the sexual organs; and these, in their turn, are but the expression of other influences played upon them by their surroundings and their own constitution."

The thyroid gland is a small, highly vascular, ductless gland, lying in the neck close to the larynx. According to Mathews¹³⁷ this small organ is enormously important in the proper development of bone, teeth, skull, brain and skin of the body; and its absence is attended by retrogressive changes in these tissues and organs. In young animals the consequences of the extirpation of the thyroids are very serious, as growth is checked. Iscovesco⁹⁸ reports that the lipid extracted from the thyroid has an activating and regulating action on the growth of immature animals, but causes a decrease in the weight of full-grown animals. It causes an especial stimulation of development of the suprarenals, ovaries and uterus in the female, and the testicles in the male. Schäfer¹⁸⁸ adds that the thyroid autacoids affect the growth of the thymus gland. Quoting further from the same writer, "The important influence exerted by the thyroid secretion on nutrition generally is no doubt responsible for the fact that hardly any organ in the body remains unaffected as a result of its complete removal or atrophy. But the secreting organs with which it may be regarded as being more specifically associated are few." Gudernatsch⁶⁵ found that feeding thyroid material to tadpoles resulted in differentiation without growth.

The facts seem to be established that extirpation

of the thyroid gland, or excessive feeding of thyroid material, both result disastrously to the animal organism.

The parathyroids are small, pale, glandular masses either embedded in the thyroids, or lying close to them or attached to the thymus gland. There are in many cases four of these bodies, two within the thyroid called the internal parathyroids, and two without, or external parathyroids. What direct influence these small organs may have on growth is not well established, and their importance may be due only to their action on other endocrine organs, particularly the thyroid. Parathyroidectomy results in death in about ten days.

Very little is known about the specific function of the thymus gland, but there seems to be general agreement among physiologists that it has some function in normal growth. It is essentially an organ of early life, being well developed at birth; and after puberty it usually undergoes retrograde changes. Robertson¹⁸⁴ has observed that the development of both the thyroids and thymus presents well marked stages which coincide closely with the cycles displayed in the growth curve of white mice. Gudernatsch⁶⁵ reports that the thymus has the power to stimulate growth in tadpoles, but lacks the power to excite differentiation. Regarding the action of thymus

feeding on other internally secreting organs, Kahn¹⁰³ writes that thymus-fed tadpoles have a better developed thyroid and a very large pituitary gland.

The hypophysis, or pituitary body, is a small organ lying at the base of the brain. It is generally described as consisting of a large anterior lobe of distinct glandular structure, and a much smaller posterior lobe; but Mathews¹³⁷ names a third part the pars intermedia, which other writers treat as a portion of the posterior lobe.

Mathews¹³⁷ concludes from a review of experimental work that the anterior lobe furnishes an internal secretion necessary for normal growth and metabolism. How this internal secretion acts, and where; whether by direct action on the tissues, or indirectly by trophic changes of the brain, thymus, sexual organs or in some other manner, is still an open question. Howell⁸⁹ reports that the posterior lobe furnishes an internal secretion which has a specific effect upon the organs of circulation and upon the kidneys. This substance is known as pituitrine.

Robertson¹⁸⁵ has named the growth-controlling principle of the anterior lobe of the pituitary body Tethelin. He found that the effects of tethelin upon the growth of white mice resemble in every particular the

effects of the administration of the whole anterior lobe. These effects consist in marked retardation of the first portion of the third growth cycle followed by acceleration of the latter portion of the third growth cycle.

Robertson and Delprat¹⁸⁷ summarize further trials as follows: "The administration of tethelin to the young subsequently to the fourteenth day, when their eyes are open and they have access to food other than that supplied to the mother, results in a noticeable acceleration of growth during the second growth cycle (second to fifth weeks), followed, upon initiation of the third cycle, by a marked retardation which evidences itself despite the fact that the administration of tethelin is discontinued at the end of the fifth week." Such results led Robertson¹⁸⁶ to conclude that factors which favor the growth of one particular type of tissue or the growth of the whole animal at a particular age may actually exert the reverse action upon another tissue or at another stage in the growth of the animal concerned.

Iscovesco⁹⁶ found that the lipoid of the anterior lobe of the hypophysis, when injected into rabbits in daily amounts of 0.5 cg. per kg., caused a general increase in growth in young animals.

"Briefly then we can say that pituitary extract (anterior lobe), when fed to young rats has a stimulating effect upon growth of the animal and upon its sexual

development and activity. Posterior lobe extract, when thus given, has a retarding influence." This conclusion, drawn by Goetsch,⁵⁹ expresses in general the results obtained by the use of extracts of the pituitary body.

According to Schäfer,¹⁸⁸ complete removal of the hypophysis results fatally. Ascoli and Legnani⁹ extirpated the pituitary bodies from dogs three to four months old and kept the animals alive up to eight months. Complete inhibition of growth ensued, which was manifested especially in the bones by deficient calcification, delayed consolidation of the junctions of the epiphyses, curvatures, and extreme brittleness. The effects of partial removal of or injury to the pituitary result in the retardation of growth, due to diminished secretion of autacoids by the gland. The failure to grow is accompanied by a tendency to adiposity, and deficient development of the sexual organs.

The pineal gland is a rudimentary organ on the upper surface of the brain. The function of this organ is still unknown, but it appears to be closely related to the sexual organs. McCord¹³⁷ found that feeding pineal glands to young chicks or guinea pigs accelerated their development.

The adrenal bodies or suprarenal capsules are two small glandular organs lying like caps on the upper poles of the kidneys. The active principle of the gland is known as adrenalin. It has a marked stimulating effect

upon the tone of the blood vessels and upon the heart, and according to Howell,⁸⁹ at least one of the functions of the adrenals is the internal secretion of this material. It is assumed that its continued formation is necessary to the maintenance of the normal metabolism of the muscular tissues. Experimental work has disclosed little knowledge, and Anon⁴ concludes from an extensive review of literature, "The weight of existing experimental and clinical evidence, then, supports the theories that the thyroid-adrenal interrelation is one of mutual stimulation; that the thyroid secretion sensitizes sympathetically innervated tissues to the action of adrenaline, and that they both act on the sugar depots of the body, producing a liberation of carbohydrates."

That the elaboration of internal secretions is a secondary function of the reproductive organs has long been known. Mathews¹³⁷ says that there are a large number of secondary sexual characters which depend upon the internal secretions of these organs, but the nature of the secretions is unknown. The work of Iscovesco⁹⁷ indicated that the lipoid extracted from the ovary, when hypodermically injected in rabbits, had a regulating and accelerating action on the growth of young animals; and a similar use of a lipoid extracted from the testicle accelerated growth in young animals and caused an increase in weight in full-grown animals.

Physiologists are in accord regarding the production of a hormone by the pancreas, and it is this substance which exerts a marked influence on carbohydrate metabolism. The exact nature of the secretion is apparently unknown. According to Howell,⁸⁹ several theories have been advanced to explain its action. One of these views is that the internal secretion of the pancreas regulates in some way the output of sugar from the liver and other sugar-producing organs. In the absence of this secretion the liver gives off its glycogen as sugar too rapidly, the sugar contents of the blood are thereby increased above normal, and the excess passes out in the urine. Again we are confronted with a maize of interactions between the autacoid of the pancreas and the other endocrine organs, and their close inter-relations are discussed at some length by Schäfer.¹⁸⁸

Very little information is available which describes the mode of action of the secretions of the ductless glands. In a recent article, Tracy¹⁹⁷ asserts that nerve stimuli are necessary for hormone action; and hormones in the blood stream are inert until nerve stimuli electrify them into action.

Garrison⁵⁴ introduces a most interesting article on ductless glands by saying that the most remarkable fact about the internal secretions is that they are correlated with one another. He writes further, "Concerning the mechanism of correlation, two prominent theories have

been advanced. The first is the doctrine of the hormones of Bayliss and Starling (1902) in which the chemical control of the body is assumed to be effected by means of hormones, or chemical messengers, which pass from the various organs and ductless glands, via the blood-stream, to other parts of the body, producing biochemical effects upon irritable protoplasmic tissues. The other theory is that of the clinicians and pharmacologists of the Vienna school, Eppinger, Falta and Rudinger, which asserts that the suprarenal and thyroid bodies act upon and are controlled by the nerves of the sympathetic system, while the pancreas is similarly related to all nerves acting upon smooth (involuntary) muscle and not originating from the chain of sympathetic ganglia.-----The interest of their theory for present purposes lies in its capacity for elucidating the action of the ductless glands and internal secretions, for behind the ductless glands and the hormones themselves there must be some controlling mechanism. The hormones of the viscera and the internal secretions of the ductless glands regulate the tonus of the nervous system, while the autonomic nerve fibers themselves regulate the action of the ductless glands, the viscera, blood vessels and all organs containing involuntary muscle."

Bayliss¹¹ warns against the adoption of this theory by writing, "Various statements have been made as to the

mutual relation of these organs, especially by Eppinger, Falta, and Rudinger, who have based elaborate theories on very slender evidence."

As to the time at which the various glands begin to function, McCord¹³³ says, "For the growth of the fetus in utero it is undetermined whether the greater influence is exerted by the maternal internal secretory system or by the newly formed glands of the fetus itself. At what period of development the embryo comes under the influence of the secretions of its own glands is not known." Upon investigation he found that physiological reactions characteristic of extracts of pituitary and suprarenal glands have been obtained from bovine fetal glands during all developmental stages in which the macroscopic recognition of the glands is possible. For the pituitary gland, this period is from the eighth week to full term. The presence of the active principles of these glands at so early a developmental period suggests that the fetus in utero may be under the influence of its own internal secreting glands as well as the maternal glands.

Fenger⁴³, who studied the same problem, writes, "The activity of the thyroid gland is measured by its iodine content. The results obtained in this experimental work indicate definitely that the thyroid glands of pigs, lambs, and calves contain iodine not merely at the time of birth

but long before. There is a gradual rise in the activity of the gland in the fetus, and this activity is increased rapidly shortly after birth, reaching its maximum in the young growing animal. The active principle of the suprarenals is also present in the fetus long before maturity and in comparatively higher quantities than in the full grown animal."

The results of later work by the same author⁴⁴ showed that both the thyroid and suprarenals of the fetus contain active principles within a few weeks after conception. Also the epinephrine in the suprarenals seemed to be present in larger and more uniform proportions than the iodine in the thyroid. The active principle of the pancreas was not present in any appreciable amount, which would seem to indicate, since the digestive glands do not function in the fetus, that by analogy both the thyroid and suprarenals of the fetus take a distinct and active part in the growth and development of the unborn animal.

Nutrition.

Having dealt with the "internal" factors which have a bearing on growth and development, there remain the "external" influences, which are controllable. We need not consider heat, light, age, gestation, and lactation, as the first two are easily regulated, and the others do not come in for consideration in a paper dealing with calf feeding. Food supply is by far the most important factor under the control of man in rearing domestic animals, and in the light of knowledge which has recently been contributed by ardent students of nutrition, it is fair to assume that further study will reveal other important additions to our knowledge. We stand now at the point where we are almost ready to relinquish much of what was considered fundamental years ago, and adopt some of the newer theories; but experience and long practice have established habits which are not easily overcome, and no doubt it is well that the practical feeder demand substantial proof of the indispensability of new methods before making radical changes in his practice. Enthusiasm has carried some of the modern investigators far afield in their search for new information, but the wise feeder will await the results of a more profound application of laboratory discoveries to

the practical feeding of domestic animals before abandoning the fruits of knowledge gained by past experience.

Requirements for a Complete Ration - Regardless of how conservative one may be on this subject of nutrition, it can safely be said that ideas on nutritional requirements are being revamped, and modern works on feeding embrace much material which was unheard of ten or twenty years ago. Until recently, protein, carbohydrates, and fats, in quantities as specified by feeding standards, were believed to fill the demands of a complete diet. Then came recognition of the fact that the mineral constituents of the diet were of importance. Physiologists studied the digestion of proteins, their assimilation and synthesis in the animal body, and soon realized that proteins were not all alike. Chemists took up the problem and analysed the proteins, thereby discovering the remarkable differences in their structure. Feeding of purified food substances brought to the notice of dieticians other heretofore unknown dietary essentials, which were first made conspicuous by their absence in supposedly complete diets. Each new discovery was the result of extensive investigational work, and one by one the new factors have been studied, analysed, and finally embodied in our fund of knowledge regarding nutrition. The bulk of this work

has been done in the past ten years, which makes it relatively modern, but such discoveries as the varying quality of proteins and the indispensability of so-called growth accessories are well established on the firm ground of fact.

There is now a general recognition of the difference in the nutritional needs of adult and growing animals, and this is summed up by Mendel,¹³⁹ as follows: "Aside from its energy aspects, the food requirement during growth is peculiar in that the intake of certain groups of nutrients, such as the proteins and inorganic salts, must exceed the demand for wear and tear, so that some excess will be available for the formation or completion of new cells and the elaboration of the tissues that especially develop in the period of growth. For the most part the materials included in the above requirement are merely those which are demanded in the usual maintenance of the grown adult, though perhaps in smaller proportions. It is not improbable, however, that the food needs of the growing organism may in part be specific and peculiar, calling not only for a little more lime or iron or protein than the non-growing individual requires, but for special substances in addition."

Food may be defined as any substance taken in by an organism and made use of for any purpose. According to Bayliss,¹¹ the uses of food may be said to be threefold; to supply material for construction of body substance; to

replace that lost in wear and tear; and to give energy for the performance of muscular movements as well as for the bringing about of endothermic reactions.

While comparatively simple compounds suffice as food for the lower organisms, more highly developed animals require food in the form of complex organic compounds already prepared by other animals or plants. As carbon, nothing less complex than glucose; as nitrogen, nothing less complex than amino-acids will suffice for these animal organisms.

Regarding the three classes of organic food-stuffs, Bayliss¹¹ writes, "For the food of the higher animals, it is usually of advantage to make up the requirements by a combination of certain proportions of fat, carbohydrate, and protein. Fat is of value on account of its high potential energy, being less oxidised than carbohydrate. It is not, of course, a necessary article of diet, since it can be formed in the organism from carbohydrates. A certain amount of carbohydrate appears to be a matter of necessity, as there is evidence that its presence is essential for the synthesis of protein. And, although the whole of the energy requirement could be supplied by protein, it would be very wasteful, since only a comparatively small amount of nitrogen is actually required. The point is that a minimum total energy value, usually expressed in heat units,

must be supplied to an animal, in order to prevent loss of body substance."

He adds, "In addition to the known organic compounds, the presence of traces of some substances, whose constitution is as yet unknown, is necessary, not only for growth, but also for maintenance. It appears, however, that there are some of these which are absolutely indispensable for growth, but unnecessary for maintenance. These "accessory factors" do not act by forming part of the constitution of definite chemical compounds such as the proteins of the protoplasm, but as "hormones" or catalysts; although the possibility of their forming some essential part of the cell mechanism, such as the surface membrane, has not yet been definitely excluded. The presence of inorganic salts in food is essential."

McCollum and Davis¹¹⁹ summarize the results of extensive feeding experiments by saying, "We must, therefore, conclude from the extensive data now available that certain at present unidentified substances aside from protein, carbohydrates, fats, and salts are indispensable for growth or prolonged maintenance."

Osborne and Mendel¹⁶⁷ recently wrote, "Progress in the study of nutrition has tended to show a far greater complexity in the nutritive needs of the organism than was appreciated or even suspected until recently. One by one the energy factor, the quantity and suitability of

the proteins, the inorganic aspects, the roughage or ballast, and the vitamine features of the diet have come into prominence and demanded recognition in the construction of an adequate dietary."

And now, to add further complications to an already intricate subject, there enters in a factor which has to do with the physical character of the ration as well as its chemical makeup. Animals exercising freedom of selection almost invariably utilize varying quantities of the seed or fruit and the leaf and stems of the plants on which they feed. Investigations into this phase of nutrition by Hart and McCollum⁷⁴ led to the following conclusion: "In our own experiments, omnivora (swine and rats) maintained sustained growth and apparent physiological vigor when the grains were intimately mixed with a roughage so as to insure a liberal consumption of the latter. With 15 or 25 per cent of alfalfa meal in grain rations we have succeeded in maintaining growth and well-being in swine, whereas without this roughage complete failure results."

McCollum, Simmonds, and Pitz,¹³² in a review of their experimental work, write, "The growth records shown make possible the generalization that it is difficult if not impossible to obtain even a moderate amount of growth over an extended period on a diet restricted to the seeds of plants. It is evident that satisfactory protein mixtures

can be had from seed mixtures and from the results shown it is further evident that certain seeds as flaxseed and millet seed contain the fat-soluble A in fairly liberal amounts. Since the water-soluble B is everywhere abundant in the seeds the cause of failure to secure growth on seed mixtures is seen to lie in the amount and character of the inorganic moiety.

"The leaf is distinctly different from the seed in its dietary properties in two respects: its total inorganic content is very high, and it is especially rich in both sodium and calcium, both of which are deficient in the seeds generally. In addition the leaf of the plant is several times richer in fat-soluble A than are the wheat, oat, and maize kernels."

From the foregoing it can readily be seen that the selection of a complete ration, as now conceived, calls into play other factors than those demanded by early feeding standards. However, the random selection practiced before nutritional knowledge had reached its present advanced position, gave satisfactory results in most practical feeding operations. Still, this does not furnish an adequate excuse for failure to apply the information that we now know is accurate.

Energy - The chief function of carbohydrate food, as also of fat, is to afford energy. It is true that part of the energy demanded by the life processes of the organism is derived from protein; and in the absence of an adequate supply of carbohydrate and fats in the ration, the supply of protein will be called on to furnish the necessary energy.

⁸⁹
Howell summarizes the functions of the carbohydrate foods, as follows:

(1) It furnishes a source of energy for the needs of the tissue cells and particularly for muscular work.

(2) The oxidation of the sugar furnishes an important part of the constant supply of heat needed by the body.

(3) The oxidation of the sugar protects the protein of the body. Experiments show that carbohydrate is much more efficient as a sparer of protein than fat.

(4) Any excess of carbohydrate, taken as food, beyond the power of the tissues to store as glycogen may be synthesized to form fat.

To further emphasize the importance of the carbohydrates in the food, the following is quoted from Mendel:¹³⁹ "Without carbohydrate in the diet the nutritive functions of a growing individual are menaced quite as readily as they are during adult life. Metabolism exhi-

bits pathologic manifestations in the lack of carbohydrates."

To the above Bayliss¹¹ adds that in the presence of carbohydrate, resynthesis of creatine into some cell protein takes place, so that it would appear that some of the nitrogen lost in wear and tear can be made use of again by the aid of carbohydrate. Further, that carbohydrates are necessary for the synthesis of protein and that amino acids are incapable of acting as sources of nitrogen to yeast in the absence of carbohydrates.

Chapin¹⁸ contributes the following: "Fats and carbohydrates serve two distinct purposes in nutrition which are equally important. They furnish energy which when expended liberates heat, and they also supply water to the cells in such a manner that it dilutes the cell contents and reduces their osmotic pressure so as to produce an automatic flow of nutriment to them from more concentrated blood, as soon as it is needed. Fats are more effective producers of metabolic water than carbohydrates."

The general functions of fat, as summarized by Howell⁸⁹, are:

(1) It provides a store of reserve food which is used by the body in case of deficiency of food or complete starvation.

(2) By its oxidation in the body it furnishes a part of the heat energy necessary to maintain the body temperature.

(3) It is a protein saver and its oxidation protects the protein from consumption.

Whether or not fats are indispensable in nutrition has not yet been definitely determined. Experimental results which would seem to point to their requirement would rest in the shadow of doubt just at present because of the recent discovery that fats, particularly those of animal origin, are quite often carriers of one of the growth accessories or vitamins; and probably the lack of this latter substance rather than the fat itself, led to erroneous conclusions.

Recent studies of conditions in certain parts of Europe, brought about by a shortage of fats due to war measures, seems to point to further importance of this class of food substances, which was hitherto not fully appreciated. People from the fat-starved districts exhibited an unusual craving for fatty food and consumed it in unusually large quantities when it became available. The physiological cause for this unsatisfied demand is not yet clear. It may perhaps be due to the craving of the appetite for energy food in more concentrated form than that in which it is supplied by carbohydrates. This view would seem to carry some weight, since most of these people received their energy from bulky carbohydrate foods.

Great emphasis need not be laid on the energy requirement of the ration; although its importance cannot be denied. In ordinary practice the feeds at hand furnish an adequate supply of carbohydrates, and if this is given in sufficient quantity to protect the protein of the body in addition to supplying the required energy, the nutritional demands for this feed will be fulfilled.

Protein - In attempting a discussion of the protein factor in growth and nutrition, one is almost overwhelmed by the accumulation of recently published experimental data. To measure the requirements of animals in pounds of protein, without consideration of the amino acid content, would be to ignore what scientists have proven beyond contradiction. . The demands of the body for certain amino acids must govern the selection of the ration, if best results are to be obtained.

Growth involves the construction of new tissue, and as protein enters so largely into this process, the protein portion of the diet of growing animals is relatively more important than in rations for strict maintenance. The highly specialized cells and organs demand specific amino acids in order to continue their normal functions, and unless the food supply furnishes these substances in

adequate amounts, physiological disturbances result, which can only be remedied by overcoming the deficiency.

In the process of protein digestion, the animal and vegetable proteins are broken up into their component parts, the amino acids. Eighteen of these so-called "building stones" have been isolated and identified, and they all enter into the structure of the proteins of the animal body. Since this is true, it is plain that the quality of the protein in the diet is just as essential as its quantity. Indeed, by a judicious mixture of protein feeds, assembled on a basis of their relative amino acid content, it is possible to greatly reduce the actual amount of protein necessary to satisfy the nutritional demands of an animal. As stated by Mendel,¹³⁹ "The possibility of growth and the extent to which it is accomplished are limited by the supply of each essential amino acid."

Biological chemists are striving to satisfy a demand for enhanced knowledge of the subject of the amino acid content of proteins, but analytical methods are tedious, technical, and expensive. The approximate amino acid content of some of the more common proteins are given in the following table:

QUANTITATIVE COMPARISON OF AMINO ACIDS OBTAINED BY HYDROLYSIS
6 & 139
FROM PROTEINS.

Amino Acids	Glia- din from Wheat %	Glute- nin from Wheat %	Zein from Maize %	Ede- stin %	Albu- min from Egg %	Albu- min from Milk %	Casein from Milk %
Glycin	0.00	0.89	0.00		0.00	0.00	0.00
Alanin	2.00	4.65	13.39	3.60	2.22	2.50	1.50
Valin	3.34	0.24	1.88	6.20	2.50	0.90	7.20
Leucin	6.62	5.95	19.55	14.50	10.71	19.40	9.35
Phenylala- nin	2.35	1.97	6.55	3.09	5.07	2.40	3.20
Tyrosin	1.50	4.25	3.55	2.13	1.77	2.20	4.50
Serin	0.13	0.74	1.053	0.33			0.50
Cystin	0.45	0.02		1.00			
Prolin	13.22	4.23	9.04	4.10	3.56	4.00	6.70
Aspartic acid	0.58	0.91	1.71	4.50	2.20	1.00	1.39
Glutaminic acid	43.66	23.42	26.17	18.74	9.10	10.10	15.55
Tryptophan	1.00		0.00				1.50
Arginin	3.16	4.72	1.55	14.17	4.91	3.01	3.81
Lysin		1.92	0.00	1.65	3.76	8.10	7.61
Histidin	1.49	1.76	0.82	2.19	1.71	1.53	2.50

A thorough application of what has already been contributed to the knowledge of protein metabolism will not be possible until complete determination is made of the quantitative demands of the animal organism for the specific amino acids; and also the quantitative amino acid content of our ordinary feed stuffs. Work on the latter part of the problem is already under way, and Gridley,ⁿ Joseph, and Slater^{63 & 64} analysed a number of feeds, with the following results:

The Nitrogen of the Amino Acids of Feedingstuffs,
Expressed in Percentage of the Feedingstuff.

Feedingstuff	Arginine N.	Cystine N.	Histidine N.	Lysine N.
Blood meal	1.281	0.096	1.179	1.360
Tankage	1.416	0.128	0.495	0.749
Wheat	0.173	0.029	0.039	0.055
Rolled wheat	0.133	0.027	0.052	0.041
Barley	0.224	0.030	0.086	0.052
Oats	0.251	0.026	0.095	0.077
White soy beans	0.726	0.038	0.329	0.351
Cottonseed meal	1.311	0.043	0.367	0.321
Alfalfa hay	0.202	0.022	0.196	0.108

Other similar analyses were made by Nollau,¹⁴⁹
of the Kentucky Experiment Station.

Although, as previously stated, much of the investigation work with reference to the quality of proteins was done recently, Underhill¹⁹⁹ writes, "The first appreciation that qualitative differences in protein composition may be of importance in nutrition was furnished by the classic experiments of Voit and Munk, who showed that gelatin could not support nitrogen equilibrium. The demonstration by Escher that the addition of tyrosine improved the powers of gelatin in establishing nitrogenous equilibrium gave rise to a series of investigations, the results of which have led to a much more complete understanding of the problems intimately connected with metabolism."

We are not concerned here with methods employed in determining the relative value of proteins and amino acids for growth and maintenance, but will summarize some of the results obtained. Feeding mixtures of purified proteins or amino acids, along with suitable quantities of carbohydrates, inorganic salts, and fats, has paved the way to astonishing revelations; but before authentic knowledge could be gained, many unforeseen obstacles had to be overcome.

The bulk of evidence at hand goes to prove that the amino acid lysine is indispensable for growth, but is not essential for maintenance. Tryptophane, on the other hand, is essential for maintenance, but adds nothing to growth. Tyrosine and cystine are also thought to have an

important bearing on maintenance.

Mitchell¹⁴³ fed mixtures of isolated amino acids to mice and found that the absence of tryptophane from the ration resulted in shortening the lives of mice; whereas tyrosine and phenylalanine had no such effect.

"Since synthesis of new protein is essential for the construction of new tissues, growth will be limited by any factor which prevents the synthesis of protein--in this case, lysine." That is one of the conclusions arrived at by Osborne and Mendel,¹⁵¹ to which they add, "In respect to the nitrogenous requirements of the organism, growth sets a standard decidedly higher than that of maintenance; for certain amino acids which cannot be synthesized by the growing organism must be furnished, not only for the maintenance functions but also for the construction of new tissue.

"Lysine is indispensable for the functions of growth. No amount of energy or protein, however abundant, has induced growth of our animals in the absence of lysine. The animal organism apparently cannot synthesize lysine, which is evidently not essential for maintenance in the sense of preservation of body weight, though it is of course impossible to say that when this amino acid is missing all functions are normally carried out. It is obvious that the possibility of growth must be limited, among other things, by the amount of lysine available."

Below is a list of proteins showing their relative lysine content in percent:

Lactalbumin	8.10%
Halibut muscle	7.45%
Ox muscle	7.59%
Casein, cow's milk	7.61%
Vitellin, egg-yolk	4.81%
Crystallized albumin, hen's egg	3.76%
Legumin, pea	4.98%
Phaseolin, kidney bean	4.58%
Glutelin, maize	2.93%
Glutenin, wheat	1.92%
Edestin, hemp seed	1.65%
Amandin, almond	0.72%
Hordein, barley	0.00%
Zein, maize	0.00%
Gliadin, wheat	0.16%

The failure of young chicks to grow on rations of low lysine content was ascribed to that fact by Buckner, Nollau, and Kastle.¹⁶ Their results were confirmed by Osborne and Mendel¹⁵⁸ in trials with foods of high and low lysine content.

A comparison of the nutritive value of certain proteins in growth led to the discovery of some of the amino acid deficiencies of these proteins by Osborne and Mendel.¹⁵³ They found that the addition of isolated cystine to the food containing nine per cent of casein renders the ration decidedly more adequate for growth; and that the addition of lysine to the nine per cent edestin food caused some improvement in growth.

The same authors¹⁵⁷ also show by experimental evidence that the quantity of tryptophane and lysine available in the diet can be made the limiting factor which determines the nutritive equilibrium and possibilities for increment of size in an individual, respectively.

Willcock and Hopkins²⁰⁵ found that the addition of tryptophane to a deficient protein dietary did not enable it to support growth of young mice, but greatly prolonged the survival of the animals. Tyrosine had no such effect. They suggest that tryptophane is directly utilized as the normal precursor of some specific hormone or other substance essential to the processes of the body.

Hopkins⁸⁸ foresees the possibility, through the study of amino acid feeding, of determining the qualitative as well as quantitative limitations of an efficient amino acid supply, and what is the most harmonious balance of amino acids for the nutrition of one animal species or another. Of his work he writes, "I have found that when

an animal is fed on food containing only tryptophane, histidine, tyrosine, lysine, and cystine; that is, five out of the eighteen amino acids of protein, there is remarkably slow loss of weight and long maintenance of apparent health. I feel it is quite possible that further experiment will show that life can be maintained on a mixture from which many of the amino acids of protein are lacking."

Arginine and histidine, according to Ackroyd and Hopkins,² may be precursors of the purines of the body, which lends them prominence and indispensability in the amino acid content of food proteins. Geiling⁵⁶ reports that these two amino acids seem to be interchangeable in nutrition.

Abderhalden¹ confirmed the findings of Willcock and Hopkins, who showed that tryptophane is indispensable for the maintenance of life in mice. He adds that the removal of lysine, arginine, or histidine destroys the life maintaining capacity of the amino acid mixture.

Regarding the efficiency of various proteins in promoting growth, Osborne and Mendel¹⁵⁹ state that lactalbumin has proved itself to be quantitatively superior to both casein and edestin, and to produce the same gain in body weight, fifty per cent more casein than lactalbumin was required, and of edestin nearly ninety per cent more. However, the addition of cystine rendered the casein much more efficient for growth.

Realizing the inefficiency of the proteins of the maize kernel to promote growth effectively, Osborne and Mendel¹⁶⁰ endeavored to determine the relative value of certain proteins as supplements for corn gluten. They write, "The efficiency of these supplements presumably depends essentially upon their relative content of lysine and tryptophane; for the addition of these amino acids, either as such, or in the form of proteins yielding them, renders corn gluten suitable for growth.

"Of the various proteins employed to supplement the inefficient corn gluten, lactalbumin is by far the most effective. Satisfactory growth is produced with smaller quantities of this protein than of any of the others recorded. The samples of brewers' grains, distillers' grains, and "vegetable albumin flour" used were the least efficient supplements tested, presumably because of their low lysine content.

"It is evident that the small additions of the more efficient proteins actually supplement the corn gluten instead of themselves furnishing all of the protein used for growth, because equivalent amounts of these proteins alone in a similar ration are incapable of inducing a comparable degree of growth. Small amounts of a superior protein are often just as efficient for growth as larger amounts of a less adequate protein.

Such information as this is bound to prove of value in practical feeding operations, when like results are gotten in trials with farm animals.

Mendel¹³⁹ submits the following list of proteins, with which, in suitable concentration, normal growth has been secured, at least for considerable periods of observation:

Proteins of Animal Origin

Casein	(Milk)
Lactalbumin	(Milk)
Ovalbumin	(Hen's egg)
Ovovitellin	(Hen's egg)

Proteins of Vegetable Origin

Edestin	(Hemp-seed)
Globulin	(Squash-seed)
Excelsin	(Brazil-nut)
Glutelin	(Maize)
Glutenin	(Wheat)
Glycinin	(Soy bean)
Cannabin	(Hemp-seed)

Proteins listed below failed to induce growth:

Legumelin	(Soy bean)
Vignin	(Vetch)
Gliadin	(Wheat or rye)
Legumin	(Pea)
Legumin	(Vetch)
Hordein	(Barley)
Conglutin	(Blue or yellow lupin)
Gelatin	(Horn)
Zein	(Maize)
Phaseolin	(White kidney bean)

The discovery of the true nutritional value of proteins from various sources, and the revelation of their amino acid shortcomings, are all valuable addenda to our store of knowledge on this many-sided question. All of these new observations have an important bearing on the problem of protein minimum. Unless our standards for requirement are made sufficiently high, they cannot be followed with safety by haphazard mixing of proteins, without consideration of the difference in efficiency of these materials derived from various sources. This feature is illustrated by a table taken from Henry and Morrison,⁸² compiled from data secured at the Wisconsin Experiment Station:

Value for Growth of Protein from Various Sources.

Source of Protein	Proportion of Nitrogen in food retained
	Per cent
Skim milk	66.2
Casein	50.6
Corn	23.7
Wheat,	26.7
Oats	28.3
Linseed meal	17.0
Wheat embryo	39.0
Corn 1/3, wheat 1/3, oats 1/3	32.0
Corn 3/5, linseed meal 2/5	32.0
Corn 3/4, linseed meal 1/4	37.0
Wheat 1/2, wheat embryo 1/2	30.0

A more complete discussion of the character and quality of the proteins of the more common feeding stuffs will be made farther on in this review.

The problem of establishing a protein minimum grows more complex when all interrelated factors are considered. McCollum and Simmonds¹²³ assert that there is

no quantity of protein or other constituent of the diet which can be designated as the physiological minimum, without the biological values of every other dietary factor being also stated. Their observations led to the statement that the early appearance of the signs of old age in rats whose protein supply was just sufficient to enable them to complete their growth at the usual rate, would make it appear that a moderate excess of protein is necessary over the amount required to maintain nitrogen equilibrium during a long period, if the optimum well-being is to be attained. Mathews¹³⁷ attributes the increase in the average stature of the population of this country to the better nourishment of the children. Since growth is dependent upon protein food, efforts to keep this down to a minimum are apt to hamper this process, and for the proper development of the body it is necessary that protein should be eaten in considerable quantities, and this protein should be of the proper makeup.

As a suitable conclusion to a chapter of much surmise and theory, a few quotations from an article by Alsberg³ will afford some suggestion as to the specific role of various amino acids, which might assist in establishing a cause for their indispensability: "There are a number of ways in which the lack of certain amino-acids may affect the functioning of the animal organism. Their lack may,

of course, make it impossible for the animal to manufacture its own tissue protein. It suffers a kind of starvation. There are, however, more indirect ways in which the absence from the diet of a necessary amino acid may be important. It has recently been found that the iodine compound of the thyroid gland is a derivative of the amino acid tryptophane. It has long been known that the normal functioning of the thyroid gland is essential to life and health. It has been found that the normally functioning gland contains the iodine compound now believed to be formed from tryptophane. It is therefore possible that when there is no tryptophane in the diet, difficulty in the formation of the iodine compound necessary for the thyroid gland results with corresponding disturbance of the gland's function.

"Adrenaline is another such substance probably derived from an amino acid. As may be seen by comparing the formulae, it is related to the amino acid tyrosine. It is formed in the adrenal glands. Adrenaline when injected into the blood causes the small blood vessels to contract and therefore the blood pressure to rise. If there is an absence from the diet of the material necessary to form adrenaline, it is conceivable that symptoms other than those of starvation might result.

Mineral Matter - One cannot proceed far in the literature on nutrition without being impressed with two factors regarding mineral metabolism. The first is the indisputable importance of certain inorganic elements in life processes, and the second is the dearth of positive knowledge of the specific functions of these materials. In the case of growing animals, the demands for construction of new tissue (bone and muscle) which involves the deposition of mineral elements, particularly calcium and phosphorus, the significance of inorganic salts in the diet is readily appreciated.

Hart, McCollum, and Fuller⁷⁵ found that on a ration extremely low in phosphorus, pigs made as large gains up to 75 or 100 pounds when starting at weights of from 40 to 50 pounds as animals receiving an abundance of this element. After reaching this point loss of weight began, followed by collapse. The percentage of ash in the skeleton of pigs on the depleted phosphorus ration was reduced to nearly one-half that of pigs receiving a normal ration.

Forbes,⁴⁶ in speaking of the prevalence of bone diseases in dry years, when lack of mineral matter in available form in the soil results in a reduction of their content in grasses, adds that the injury is most marked in young, growing stock and in milking or in pregnant females.

In his recent book on nutrition, Armsby⁶ writes, "But while it seems scarcely possible to make any definite quantitative statements regarding the necessary ash supply of growing animals there is abundant evidence of the evil effects of an insufficient supply. In particular, a deficiency of calcium, as already indicated, may have serious consequences both directly and on account of the fact that such a deficiency generally connotes an acid ash."

Aside from their undeniable consequence in growth, mineral elements have a wide variety of functions in animal metabolism generally, and these are enumerated by Forbes⁴⁷, as follows:

As bearers of electricity the mineral elements dominate the whole course of metabolism.

They conduct nerve stimuli, and play a leading role in the general process of cell stimulation.

They govern the contraction of the muscles, including those of the heart.

They compose the central agency for the maintenance of neutrality in the blood.

They enter into the composition of every living cell.

They compose supporting structures.

They assist in the coordination of the digestive processes.

They activate enzymes, and through their control of the chemical reaction of the blood and tissues they govern enzyme action.

They unite with injurious products of metabolism, and render them harmless or useful.

As catalyzers they alter the speed of reactions, and the rate of metabolism generally, as measured by oxygen consumption.

Through their effects on osmotic pressure they govern the movement of liquids, and maintain the proper liquid contents of the tissues.

Through their effects on surface tension they participate in the mechanism of cell movement.

Through their control of the imbibition of water by the colloids they govern respiration.

Finally, they control the state of solution, precipitation, mechanical aggregation, chemical association and ionization of the colloids which compose living tissue.

That the inorganic factor in nutrition has not attracted more attention may be largely due to the fact that most of the rations fed on the farm will supply the required substances in sufficient quantity. However, Forbes⁴⁸ calls attention to the fact that modern tendencies in stock feeding give this subject of mineral requirements special importance. The forced feeding of our early maturing meat animals and the selective improvement of our

dairy cows for greater productive capacity call for a higher percentage of mineral nutrients in foodstuffs than was necessary in the old days of less intense production.

The ash content of milk helps to make it such a desirable and complete food for young animals, and any practice which limits the amount or offers substitutes, can be indulged in safely only when those articles in the diet which displace the milk are carriers of the mineral elements so essential for growth. Since the "growth impulse" is believed to reside largely in the skeleton, failure on the part of the feeder to supply the materials required for construction of the bony parts will lead to disaster. Some farm feeds, such as timothy hay and corn, are notoriously deficient in mineral content. On the other hand, leguminous roughage analyzes high in ash, particularly calcium, which enters so largely into the makeup of bone. Its use cannot be too highly recommended for young and growing animals.

On this same theme, McCollum, Simmonds, and Pitz¹³² write, "The leaf is distinctly different from the seed in its dietary properties in two respects: its total inorganic content is very high, and it is especially rich in both sodium and calcium, both of which are deficient in the seeds generally."

Aside from the more common elements, calcium, magnesium, and phosphorus, which stand out so prominently

in the demands of mineral metabolism, attention might be called to iodine, which is essential for the proper functioning of the thyroid gland. Iron also holds a place of importance because of its function in the haemoglobin of the blood of carrying oxygen, and because the iron content of milk is so markedly low. Few, if any, accounts of shortages of the other lesser mineral elements are found in the literature on nutrition.

Reassurance can be found in the following quotation from Osborne and Mendel:¹⁶⁴ "The fact that the growing animal can fully supply from inorganic sources its requirements for the elements specially discussed in this paper (magnesium, sodium, chlorine, potassium, calcium, and phosphorus) emphasizes anew that it is unnecessary to consider the presence of calcium, phosphorus, and iron, for example, in natural foods to the degree that is currently believed. Any shortage of an essential inorganic element can be suitably remedied under ordinary conditions by the use of its salts. For feeding farm animals, where the lack of calcium and phosphorus in their grain rations is always encountered, the demonstration that complete nutrition can be attained upon diets in which the inorganic ingredients are supplied in the form of their commercial salts has a significance that is just beginning to be appreciated."

The question is a big one, and it goes back to the maintenance of the fertility of the land in order that it may produce feeds with ample mineral content to supply the needs of the animals which are fed on these products of the land. For the calf feeder it means the utilization of feeds which are rich in calcium, magnesium, and phosphorus.

Accessory Substances - "Unidentified" is the term which science most often applies to two or more substances which have been discovered to be essential to the continuation of growth and normal nutrition. Because of the fact that no means has as yet been discovered for isolating these products from their carriers, there is still much controversy as to their chemical nature, and such of their properties as have been identified, are known mainly by the effects they produce. Their existence became most strikingly evident through their absence from what were deemed complete diets. Hopkins, McCollum and Davis, Hopkins and Nevill, and Osborne and Mendel¹³⁷ found, in testing the efficacy of various pure proteins and inorganic salts in promoting the growth of young white rats, that artificial diets containing some protein, such as edestin, albumin, or casein, some inorganic salts like those of milk, some starch, and lard, nourished the animals for a time, but that sooner or later they ceased to grow, so that they rarely attained more than two-thirds of the normal weight for rats of their age. The substitution of butter for the lard in the ration, brought about a resumption of growth to normal.

Experiments with diets that produce the deficiency disease known as beri-beri, resulted in the revelation that there is another essential dietary substance beside the

one referred to above. The former may be designated as fat-soluble, while the latter is water-soluble.

The nomenclature of these essential substances is still in controversy, as scientists seem unable to agree on a uniform means of designation. It is possible that the confusion of names will be set aside when the products have been isolated and identified. Funk prefers "vitamines", McCollum adopts "fat-soluble A" and "water-soluble B", and Osborne and Mendel choose to call them "food hormones". "Growth accessories" and "dietary essentials" have also been used in the literature on nutrition. Regardless of the name adopted, they seem to fall into two general classes, which may be designated as fat-soluble and water-soluble. Of the former, there appears to be but a single substance; but it is possible that a group of water-soluble "vitamines" may exist, each with a specific action. There is lack of unanimity of opinion among the leading investigators regarding the water-soluble accessories. Funk inclines to the opinion that there is a group of such substances, and that each of the so-called deficiency diseases, beri-beri, scurvy, pellagra, and rickets, has its specific vitamine. In contrast, McCollum insists that only two deficiency diseases exist, i.e., xerophthalmia and beri-beri, the former being due to a lack of fat-soluble A; whereas the latter is caused by a lack of water-soluble B in the diet.

¹²¹
His contention is that this water-soluble B is but a single

substance.

We are indebted to the ceaseless activity of scientific investigators for more extended knowledge of the presence of these "food hormones" in animal and vegetable products. The latest list of articles in which they are found was compiled by Osborne and Mendel,¹⁶³ and is given below.

Fat-soluble	Water-soluble
Butter fat	Milk
Egg yolk fat	Rice
Cod liver oil	Wheat embryo
Beef fat	Cotton seed
"Oleo-oil" margarines	Pancreas
Pig kidney fat	Maize kernel
Maize kernel	Wheat kernel
Rye	Oat kernel
Wheat embryo	Kidney beans
Wheat kernel	Yeast
Cotton seed	Soy beans
Cabbage leaves	Maize embryo
Clover leaves	Peanut meal
Oat kernel	
Soy beans	
Sunflower seed	
Alfalfa leaves	
Flax seeds	
Hemp seed	
Millet seed	

With regard to the distribution of the vitamine in the different portions of the kernel, Chick and Hume¹⁹ report that in both rice and wheat grain the antineuritic vitamine is concentrated mainly in the germ or embryo, but it is also present to a less degree in the bran, probably in the aleurone layer. In the case of maize grain, the embryo also possesses marked antineuritic properties.

Milk is listed as one of the carriers of the water-soluble vitamine, but Chick, Hume, and Skelton²⁰ discovered in feeding guinea pigs that milk is evidently poor in the anti-scurvy accessory factor. Where it was relied on to supply all of this substance, practically a complete diet was necessary to induce satisfactory growth and prevent the development of scurvy.

Osborne and Mendel¹⁶⁶ obtained similar results in feeding rats where milk was used as the source of water-soluble vitamine. They write, "Not until at least 16 cc. of fresh milk per day were supplied along with the food mixture, was anything approaching a normal rate of growth secured. Even this amount sometimes failed." "It seems advisable for the present in practice to use a liberal amount of milk when it is depended on to supply any considerable proportion of this necessary food factor."

A difference in the efficiency of butter fat over beef fat for inducing growth in rats is attributed to the greater abundance of the fat-soluble A in butter

fat. This observation was made by Osborne and Mendel.¹⁵⁴
 The same reason would account for the relative efficiency of most of the carriers of this factor.

With reference to the minimum requirements of these substances for maintenance and growth, McCollum and Simmonds¹²² write as follows:

"Our results indicate that there is no low plane of intake of either of these substances which can be said to maintain an animal without loss of vitality. When the minimal amount necessary for the prevention of loss of weight is approached the life of the animal is jeopardized if the diet is persisted in.

"Within certain limits growth is proportional to the supply of the fat-soluble A and water-soluble B in the diet, all other factors being properly adjusted.

"The animal can tolerate being limited to a very low intake of either the dietary A or B much better with an otherwise excellent diet than when it is less well constituted.

"Without exception the records indicate that it is dangerous procedure to attempt to fast an individual selectively for one or both of these dietary essentials.

To the above might be added the results secured by Steenbock, Boutwell, and Kent.¹⁹³ They found that in the case of rats as small an amount as five per cent of alfalfa in the ration provided sufficient fat-soluble vitamins for

normal growth, reproduction, and the rearing of some young.

It is natural to assume that little is known about the properties of these vitamins, since the substances have not yet been isolated and identified.

Halliburton and Drummond⁷⁰ summarize the work carried on to determine the properties of the fat-soluble vitamin, as follows: "As regards the nature of the substance itself, our knowledge is very small. Osborne and Mendel found that it resists treatment with steam, and their results were confirmed by the work of McCollum and Davis, who found it present in the ether extract of boiled eggs. It is apparently able to withstand the process of hydrolysis of the accompanying fat, for McCollum and Davis were able by this means to devise a method for transferring the active substance to a food originally deficient in it. Osborne and Mendel found that the storage of butter for considerable periods does not markedly affect the accessory substance, but that butter oil may entirely lose its content of the active substance when stored for a year. The accessory substance is apparently soluble in alcohol, but it is not always present in the ether extracts of substances originally containing it. On the other hand, it is found in the ether-soluble portions of eggs and butter; whilst on the other hand the ether extracts of many vegetable products known to be rich in the product are not always active, as

has been recently shown by McCollum, Simmonds and Pitz. It is frequently suggested that the substance is a member of the class of lipoids, and this view has found a considerable number of adherents. A recent theory regards the accessory substance as being held in some form of chemical union in the plant cells, thus accounting for the failure of ether to extract it. This union is broken during the assimilation of the plant food stuff by the animal, and since the active substance is readily soluble in fats, it forthwith accompanies them into the animal body."

Ramsden,¹⁷⁷ describing the same substance, writes, "It is slightly soluble in water but much more so in oils, ether, and hot alcohol. It is very resistant to ordinary cooking operations, but is slowly destroyed by prolonged exposure to day light. It has not been identified with any of the chemically known constituents of plants and animals. It is either completely free from phosphorus and nitrogen, or alternatively, it is active in incredibly small amounts. As found in the higher plants, it is insoluble in ether, oil, or hot alcohol."

McCollum¹¹⁸ states that fat-soluble A may be stored in the tissues (fat) of the mother and secreted into the milk; but it is not abundant in the milk unless present in the diet of the mother. He adds that it cannot

be synthesized in the animal body. However, due to her ability to store it, the nursing mother can supply milk which is better food than the products from which it is elaborated, for feeding young.

According to McCollum,¹¹⁸ the fat-soluble A in butter fat is not destroyed by heat, as might be applied during cooking operations, and even the fat of evaporated milk contains the substance. Leaves such as celery tops and those of the immature alfalfa plant, when dried in the ordinary way, are still good sources of the fat-soluble A.

In contradiction, Steenbock, Boutwell, and Kent¹⁹³ found that heating of butter fat leads to the destruction of its vitamine. This is brought about when butter fat is heated for four hours at 100 degrees. They surmise that the failure of other investigators to note this destructive action of heat was undoubtedly due to the high initial content of the fat-soluble vitamine in the material studied. The destructive process is evidently a reaction of low velocity. With large amounts of vitamine present and with heat treatment for a limited period of time, sufficient amounts of the vitamine remained to satisfy all the requirements for normal growth in the experimental animals.

³⁵ Drummond summarizes the properties of the water-soluble growth accessory, as follows: "The antineuritic substance is apparently only partially soluble in alcohol. This solubility is very small in absolute alcohol, but

becomes greater as more dilute alcohol is used. It is usually described as being insoluble in ether, chloroform, and other lipoid solvents. It is absorbed by animal charcoal; whilst a colloidal aluminum silicate has recently been used for quantitatively adsorbing the antineuritic substance. Most authors agree that the substance is unstable under certain conditions to alkali. With regards to the effects of acids, most authors agree that it is stable even when they are applied hot and in relatively concentrated condition. The degree of thermostability possessed by the substance has been noted by several investigators, who appear to agree that temperatures below 100 degrees do not exert a deleterious effect. Higher temperatures, however, are usually considered to injure its activity."

To this he adds, "Experimental evidence is given which demonstrates that certain of the properties possessed by the antineuritic substance and the water soluble accessory growth factor B are very similar. These facts support the view that the substances are identical."

¹⁷⁷
Ramsden describes the same substance as follows, "It is neither a protein, fat, nor a carbohydrate; nor indeed any of the known constituents of plants or animals. It is free from phosphorus, insoluble in absolute alcohol, ether, benzene, acetone, or oils, soluble in water or 90% alcohol, and is adsorbed by Fuller's earth or animal charcoal. It is resistant to 5% sulphuric acid."

McCollum, Simmonds, and Pitz¹²⁷ are of the opinion that water-soluble B is necessary to the organism throughout life, and McCollum and Kennedy¹²⁰ state that fat-soluble A appears to be dispensable when maintenance alone is involved.

McCollum, Simmonds, and Pitz¹²⁵ are responsible for the hypothesis mentioned above, that the fat-soluble A is in chemical union in the plant tissues and in a complex which is not soluble in fat or in ether. In digestion and absorption it is set free, and being readily soluble in fats, accompanies the fats in the animal body.

There is much speculation as to the manner in which these substances function, and the following quotation from Osborne and Mendel¹⁶² illustrates this uncertainty regarding the action of the accessory factor in yeast: "How does the yeast exert its beneficial effect? Does it merely add something which renders the food more palatable and so stimulates the animal to eat more liberally of it? Or does it exert some favorable influence upon the metabolism of the rat, and thus improve its general condition so that more food is consumed? Satisfactory growth is associated with liberal eating; but whether the animal eats because it grows or grows because it eats is a difficult question to settle."

Bywaters¹⁷ writes, "It may be asked in what way do these vitamins act? Careful investigations by Hopkins

showed that in his experiments involving the addition of small quantities of milk, not the slightest difference in the percentage extent of absorption could be discerned whether the milk was added or not. It is also not a question of appetite. The minuteness of the quantities of these vitamins which are requisite to maintain normal processes of life suggest that they must have something to do with the production of some of the essential hormones, internal secretions, enzymes, etc. in the animal organism."

A study of the glands of internal secretion of birds which died of polyneuritis was made by Funk,⁵³ and he found that there was great diminution in size of the glands examined, and marked degeneration of the cells. In most cases the marked atrophy was due to the disappearance of the cells, the framework of the gland alone remaining. The most marked change was in the thymus.

Drummond³⁶ discredits the theory that shortage of the water-soluble substance has an ulterior effect on the endocrine glands, and found that dessicated pituitary gland, thyroid, thymus, testicle, and ovarian tissues were deficient in the water-soluble B. He concludes that the cause of the fatal decline which unavoidably follows a deficiency of the water-soluble substance has not been determined. Symptoms of nerve disorder were noted before death in three cases.

38
Recently Dutcher and Collatz reported that the water-soluble B does not act as a direct activator of catalase, but instead probably stimulates the organism to greater production of catalase.

The problem is still theoretical, but this much we do know; that there are at least two accessory substances, of unknown composition, which must be present in the diet if maintenance and growth are to proceed normally.

Dietary Deficiencies of Some Feeding Stuffs -

An extensive study of the physiological effects of rations balanced from restricted sources has been carried on at Wisconsin Experiment Station, and the first results of this work were reported by Hart, McCollum, Steenbock, and Humphrey.⁷⁶ The general plan of their experiments was to feed animals on rations made up entirely from a single plant source, such as wheat, oats, and corn. The results secured were striking, and seemed to offer astounding possibilities for further research; as it became clear that there was a distinct and important physiological value to a ration, and that chemical methods of analysis were inadequate to furnish full criteria of the nutritive value of a feed. These experiments have been often referred to and discussed in the literature on nutrition, and are cited here merely because they occupy such a prominent position and led to the discovery of new factors in nutrition of so much importance.

In order to take full advantage of scientific knowledge in practical feeding operations, it is necessary that one should have some information about the qualities of the food stuffs in every day use. By the use of what is known as the biological method of analysis, investigators have found a means by which it is possible to determine what factors are lacking in the makeup of food products.

McCollum¹¹⁸ reports that the list of seeds examined in this way includes wheat, corn, rice, rolled oats, rye, barley, kaffir corn, millet seed, flaxseed, pea, and navy and soy beans. These all contain proteins which are of distinctly lower biological value for growth than are the proteins of milk; and all are poor in the same three inorganic elements, calcium, sodium, and chlorine. All are, with the exception of millet seed, below the optimum in their content of the dietary factor, fat-soluble A. He adds that these three dietary factors must be improved before any one of these seeds becomes complete from the dietary standpoint.

The common belief that dietary deficiencies can be largely overcome by the use of complex mixtures is discredited to some extent at least by McCollum and Simmonds,¹²⁴ who say, "Even with food mixtures derived from two to five seeds we have not found it possible to induce any growth in young rats when the animals were given distilled water to drink, and were therefore, afforded no inorganic salt supply other than what was contained in the seeds."

Comparative values of variously derived proteins are set forth as follows, by McCollum and Simmonds:¹²⁴
"Judging from our studies on the physiological minimum of protein for maintenance in the rat, if milk proteins are

assigned the value of 100, oat and millet seed proteins would be assigned a numerical value of about 75, wheat, maize, and rice proteins 50, flaxseed proteins 40, and the proteins of the pea and navy bean about 25." They further state that there is some improvement in the biological values of the proteins of mixtures of seeds in all cases over the values of the proteins of the seeds fed singly. This is a contradiction of a previous observation made by McCollum¹¹⁶ that where the three grains, (wheat, oats, and corn) were fed together in equivalent amounts there did not appear to be a very appreciable favorable influence on the nitrogen retention of pigs due to the supplementing action of the proteins from one source on those from another.

By investigating the dietary properties of wheat biologically, McCollum¹¹⁸ found that the wheat grain is deficient in its mineral content, its proteins are of poor quality, and its content of fat-soluble A is insufficient.

McCollum, Simmonds, and Pitz¹²⁹ were unable to make up a ration containing wheat proteins only, which was adequate for rearing of young. However, they found that as small an amount as fifteen per cent of whole wheat as the source of the water-soluble B, suffices for the completion of growth in the rat. The same investigators¹³⁰ are inclined to the belief that lysine is the only amino

acid whose addition to the wheat protein mixture raises its biological value.

Hart, Miller, and McCollum⁷⁷ offer another criticism of the wheat grain, and the results of their work in feeding swine would indicate that too large a proportion of whole wheat in the ration introduces such a mass of toxic material as to render it impossible for the animal to complete its cycle of life, even in the presence of a considerable quantity of all known factors necessary for growth. This toxic principle, according to McCollum, Simmonds, and Pitz,¹²⁶ resides in the wheat embryo.

The oat kernel, according to McCollum,¹¹⁸ is deficient in its inorganic content, the quality of its protein is incomplete, and it lacks a sufficient amount of fat-soluble A to support normal nutrition. It carries a liberal supply of water-soluble B.

Lysine apparently is the amino acid, the deficiency of which makes the protein content of the oat grain inadequate for growth. This assertion is made by McCollum, Simmonds, and Pitz.¹³⁰

The same writers¹³¹ say, "It is not necessary to assume the presence of something toxic in the oat kernel to account for the injury which results from the presence of a high content of oats in a monotonous food mixture taken over a considerable period. Oats produce feces of

a pasty character which makes their elimination difficult, and in all probability tend to debilitate the animal.

"When the oat kernel is supplemented with casein, a suitable salt mixture, and butter fat, growth may proceed to the normal adult size at the normal rate in some animals, but in general growth is slower than the normal rate.

To the above might be added the statement by Funk⁵² that the symptoms that develop in rabbits fed on oats are due possibly to acidoses and not to scurvy.

According to Hogan,⁸⁴ when corn grain is fed to rats as the sole dietary, the mineral constituents are the first limiting factor, and then the protein; and in the case of swine, the reverse is true. He⁸⁵ later found that the most important mineral deficiency of corn is calcium; and that tryptophane is the first limiting factor in the proteins of the corn kernel, and then lysine. McCollum¹²⁸ and his co-workers report that the maize kernel contains both the unidentified dietary factors, but the fat-soluble A is present in too small an amount for the maintenance of growth at the maximum rate in rats. The water-soluble B is present in abundance. They were unable to nourish young rats satisfactorily on a diet restricted to the germ of the maize kernel, or to mixtures of the germ and whole ground maize.

165

Osborne and Mendel¹⁶⁵ also write, "We have never yet been able to feed a sufficient quantity of the proteins of the maize concentrate to effect normal growth, although we have evidence that all of the essential amino acids are present in some part of the seed."

Barley has been tried out recently by several experimentalists, and Steenbock, Kent, and Gross¹⁹⁴ found that its primary growth determinant is inorganic salts. The protein is also incomplete and there is a deficiency in fat-soluble A. Barley contains an abundance of the water-soluble vitamine.

165

Osborne and Mendel¹⁶⁵ differ in their opinion regarding the protein of barley. Their experience with barley concentrates shows that the proteins from this source are adequate to promote growth when they are furnished in sufficient abundance.

Millet seed and flaxseed, while not as commonly used in some sections as corn, oats, and wheat, frequently enter into the ration of farm animals. McCollum and Simmonds¹²⁴ contribute the following: "Millet seed and flaxseed are both distinctly better as sources of the fat-soluble A than are the cereal grains, wheat, maize, and oats. Mixtures of seeds containing one of these may, when properly supplemented with calcium, sodium and chlorine, support animals in apparently good health."

Cottonseed meal has become an appreciable factor in feeding operations; although not usually recommended for growing animals. According to Osborne and Mendel,¹⁶¹ it contains a sufficient quantity of the water-soluble vitamin, and their results would indicate that the protein content is efficient for growth, but they doubt the completeness of its mineral content, and apparently there is lack of a sufficient supply of the fat-soluble A.

Richardson and Green¹⁸² summarize their trials in feeding cottonseed meal to rats, as follows: "Our results indicate that cottonseed meal does not contain sufficient minerals for growth, is not actively toxic, contains efficient protein, and perhaps fat-soluble growth-promoting substances, similar to those of butter fat, but in less adequate quantities."

Milk enters so largely into the nutrition of young animals, that the complete omission of some discussion of its value as a food would leave this work incomplete. It is recognized as the most complete food for young mammals, and without some understanding of the factors which give it its wonderful efficiency in nourishing and promoting growth, the problem of supplying a substitute or supplement for it would remain an enigma to the feeder. McCollum¹¹⁸ states, "Milk contains all the essential food elements, and human experience teaches us that the proportions in which they occur in this product are much

more satisfactory than in many other natural foods."

The excellent quality of the proteins of milk for maintenance and growth is generally recognized; its ash content is highly efficient with the exception of a shortage of iron; the fat soluble accessory is present in abundance in the milk fat; but there is some question as to the adequacy of the supply of water-soluble vitamins in milk. As previously recorded, it is recommended that it be fed in liberal quantities when relied on as the sole source of supply of this factor in the ration. However, since milk is usually supplemented with cereal grains, which abound in water-soluble B, the limited presence of this material in the milk part of the diet is not deemed of great significance.

McCollum¹¹⁸ designates milk and the leaves of plants as "protective foods", and warns against their omission from the diet.

No very extensive data are available on the nutritive properties of the class of feeding-stuffs commonly known as "roughages". Their importance in the ration is recognized, and warnings against their omission are plentiful. These feeds consist of the stems and leaves of plants. McCollum's work¹¹⁸ along this line is noteworthy, and the following quotation from his recent book is enlightening: "The leaf proves to be a very different thing from the seed from the dietary standpoint. The dry leaf

usually contains from three to five times as much total ash constituents as does the seed, and is always especially rich in just those elements in which the seed is poorest, viz., calcium, sodium, and chlorine. It follows, therefore, that the leaf supplements the inorganic deficiencies of the seed. The leaf, in most cases, contains much more of the dietary essential, fat-soluble A, than is found in any seed. The leaf contains protein and amino acids which result from digestion of proteins. The leaf proteins appear, from the data available, to supplement and enhance in some degree the value of the seed proteins with which they are combined." He attributes the difference in nutritive properties of seed and leaf to their varied functions, the former being largely a reserve food supply; while the latter is composed of active cells, where plant tissue is elaborated; hence a supply of complex materials is always present.

Leguminous roughage ranks especially high in this class of feed stuffs, because it is known to be a carrier of calcium, and its protein content is relatively high and of such a character as to correct some of the deficiencies of the proteins of the cereals in conjunction with which it is usually fed.

Effects of Retarding Growth.

Since the growth impulse is only given full play when the ration supplies ample materials for the elaboration of new tissues, it would be interesting to know what, if any, permanent effect retarding or checking growth by insufficient food would have.

203

Waters, in his work with steers, discovered that what he terms the law of physiological compensation applies with particular force in the matter of growth. He says that the animal has recourse to any or all of the following ways to reach a normal size:

First, by growing steadily from birth to maturity, as with a uniform and ample food supply.

Second, by storing fat in a period of abundant food supply to assist in tiding over a limited period of sparse food supply without serious interruption of growth.

Third, by prolonging somewhat the growth period. Just to what extent this is possible cannot be estimated, but results already obtained indicate quite clearly that an animal when sparsely fed through the early part of its life may grow after the time when an animal that was normally nourished is matured and has ceased to grow.

Fourth, by an increase in the rate of growth in

a period of liberal feeding following a period of low nourishment and low gain. In other words, an animal that is below the normal in size at a given age, through poor nourishment, apparently has the capacity, when liberally fed, to compensate for this loss in a measure at least, by an increased rate of gain.

⁷ Aron remarks that there are two forces at work in the growing animal which to a certain extent oppose each other, the tendency to grow and the tendency to maintain life. The former is believed to reside mostly in the skeleton, and he observed that if a growing dog is kept at a constant weight, the bones continue to increase in weight and therefore to grow, although not quite so rapidly as in a normally fed control animal. ²⁰³ Waters observed the same condition.

¹⁹⁸ Trowbridge, Moulton, and Haigh, in a recent publication, state, "When young beef animals in good condition are put on a ration insufficient to provide for a normal growth there is a very persistent tendency to grow in spite of the feed restrictions. Much of the surplus fat will be used for energy, and growth of both lean flesh and skeleton will continue. Later, with continued feed restrictions, the animals will draw on both the residual fat supply of the soft parts and also on the protein of the soft parts to maintain existence and to promote a normal growth of the skeleton, which even includes the

storing of fat in the skeleton."

There is some division of opinion as to the permanent effect of retarded growth. One view is expressed by Aron⁷, when he concluded from his experiments that it is possible by supplying suitable amounts of food to maintain a dog in an emaciated condition, apparently in good health, and at the weight of a puppy, for nearly a year, while its weight at the end of the year should be three times as great. If such an animal is thereupon fed amply, it fattens and rounds out, but does not reach the size of a control animal which from the beginning has been normally fed. It is unable to make good the growth suspended by the long restriction of food. It is Aron's belief that the growth impulse lasts only throughout that period of the animal's life when it normally manifests the power to grow, and if held in check until that period has expired, the impulse is lost forever. Another statement made by Aron⁸ is that the age at which we stunt an animal by restriction of diet is of great importance, and it seems very probable that the restriction of diet is more deleterious the younger the animal is, especially during the period of lactation.

All of the foregoing is contradicted by Osborne and Mendel,¹⁵² and their contention is that the capacity to grow is only lost by the exercise of this fundamental property of animal organisms. Their observations are that

satisfactory resumption of growth can be attained not only after stunting by underfeeding, but also after the cessation of growth which results when the diet contains proteins unsuitable for the synthetic processes of growth. Furthermore, they¹⁵⁵ state that the size or age at which the inhibition of growth is effected does not alter the capacity to resume growth. It might be well to append their own wording of a doubt regarding this practice. "The methods of partially retarding or completely suppressing growth are too varied and unlike to permit final answer as yet regarding the outcome of all of the procedures of inhibition for the subsequent welfare of the individual. Our observations apply to the effects upon size and a few other incidental features."

The same authors¹⁵⁶ observed that after periods of retardation, growth proceeds at an accelerated speed. This is somewhat in line with the statement made by Mumford,¹⁴⁸ that the animal subjected to severe conditions of feeding during its early life evidently has a greater capacity for growth, and makes better use of the food consumed, than does the animal that received a generous ration during the same period of its life. He states further that there can be no question but that under certain conditions a significant check to the development of an animal may actually increase the rate of growth during the later periods of its life.

Thompson and Mendel¹⁹⁶ likewise say, "In correspondence with the observations of previous investigators, the present experiments have shown that the resumption of growth, after the suppression of growth during periods of varying lengths at different stages of the growth cycle, ensues at a greatly accelerated rate."

Regarding the economy of this practice, it is their opinion that ordinarily the food requirement during any considerable primary period of maintenance without growth is sufficient to overbalance any economy in food during the period of accelerated growth.

Hopkins⁸⁷ views apparently coincide with the above, for he writes, "The slow growing animals, while necessarily using less than the others for growth purposes, would require relatively more for maintenance. It is clear that if two sets of animals, rapidly differentiating in respect to body weight, continue to consume the same amount of food per unit of weight, those which grow faster have available a continuously increasing fraction of the whole for purposes of growth, since the demands for maintenance continue to become relatively less."

More data is needed to make any of these statements carry conviction.

There is still some doubt as to whether or not stunting has any deleterious effect on the animals later

welfare. It is well to bear in mind that in rearing dairy calves, we are dealing with animals that will prove most profitable when their early care and handling is such as to insure complete development of body and vital organs. The production of milk throws an enormous strain on the cow, and any preliminary system of management which would impair the proper functioning of her powers to reproduce herself and to elaborate milk in generous quantities, would in the long run defeat its end and result in disaster.

Eckles³⁹ has demonstrated that low plane of nutrition retards growth, and Regan¹⁸¹ found that lactation checks growth. Combining these two factors, we are almost certain to permanently stunt our animals. Since heifers must be bred to freshen before they are fully matured, it would appear to be the better practice to aid them by adopting a system of management which will insure unimpaired growth from birth.

Summary and Practical Application.

A resume of all that science has discovered in the last two decades in regard to nutrition of animals reveals the fact that there is still much veiled in uncertainty and doubt. Theory and hypothesis are still rife. The chemist has not kept pace with the enormous demand for more complete analyses of feeding stuffs. In adopting much of what is new we are sailing uncharted seas, and it is wise to cling to our compass, lest we meet with disaster. The feeding standards must still be our main reliance and guide in formulating rations for our animals. They are not above criticism, but we are not yet prepared to take such a radical step as the complete abolition of these guiding principles.

With the feeding standard as a foundation on which to build, our structure, the daily ration, can be made as modern and up-to-date as our facilities permit and economy justifies.

Granting always that nature has provided the young animal with that unknown force, the stimulus to grow, and that it is equipped with a complete set of normally functioning organs, we can proceed to supply the nutritional demands of the animal according to rules and tables; always

varying our practice sufficiently to meet the idiosyncracies of the individual in so far as is practicable.

In approaching the problem of calf feeding, it is well to bear in mind that we are dealing with a young animal, whose vital organs are mostly in process of development and not yet attuned to digestion and assimilation of a great variety of foods. Milk is the natural food for young mammals, and we should recall all that has been said of its value as growth-producing material, when we endeavor to use a substitute or greatly reduce the quantity below the requirements of the animal. Replacing "nature's balanced ration" with a complete substitute has baffled our best feeders, and it can be safely said that for very young calves it cannot be done.

Experience would tend to prove that requirements of energy and protein for both maintenance and growth as expressed by the feeding standards are ample. With this in mind, we turn to our supply of feeds to determine the materials we have to work with in compounding rations. The problem of the energy supply is usually of simple solution, as most farm products furnish carbohydrates and fats in abundance.

There has been a suggestion of the special efficacy of lactose, the principle carbohydrate of milk, for feeding young animals; but there is no reason to believe

that it cannot be replaced by other carbohydrate foods without danger to the welfare of the animal. The milk fat of itself is not indispensable in nutrition, but it has enhanced value as a growth feed because of the fat-soluble accessory which it carries. The energy which it supplies can be contributed from other sources.

The problem of protein substitution is more complex, when we consider the high degree of efficiency exhibited by milk proteins in inducing growth and when used to supplement other proteins qualitatively incomplete. Lactalbumin and casein rank respectively first and second of the proteins in their content of lysine, that amino acid which is so involved in the functions of growth. Perhaps it is supplied in overabundance by milk, but right here is where our new knowledge breaks down, as no one has as yet determined the exact amount of this essential amino acid necessary to fulfill the demands of growth. Tryptophane and tyrosine are also plentiful in milk proteins.

Most of our common cereals have the similar deficiency of incomplete proteins, and low lysine content is characteristic of the entire group. For this reason they fall short when used as the sole source of protein to replace the milk proteins. The proteins of alfalfa hay are more liberally supplied with lysine, which affords

one point in favor of this article in the calf ration. Blood meal has gained favor among calf feeders, and this may be attributed to its relatively high lysine content. The animal proteins are all richer in this growth attribute, and blood meal apparently has a place in the milk replacing feeds until such a time as the calf is old enough to secure its supply of lysine from the hay and grain which it consumes. At this time, the use of a well selected grain mixture carrying protein from different sources, supplemented with leguminous roughage, preferably alfalfa hay, should furnish the animal with protein in sufficient quantity, and complete from a qualitative standpoint so far as varied amino acid content is concerned.

It would appear that with augmented knowledge as to the amino acid content of feedstuffs, and the specific demands of the animal for these various acids, the possibility will arise of reducing the present schedule of protein requirements for growth. However, until this information is available, it is well to furnish this raw material in abundance, looking particularly to its content of the indispensable lysine.

Mineral matter in the rations of calves only becomes an acute problem when substitutes are offered for milk, because of the completeness of its ash content.

The cereal grains lend no assistance in making good the shortage, as they are all notoriously low in calcium, sodium and chlorine. The latter elements are easily supplied in the inorganic form, but the importance of calcium in bone construction makes it imperative that this be furnished to insure proper growth. Again we turn to the legumes, and alfalfa hay gains a second point for a place in calf rations. Aside from this deficiency of calcium, which is taken care of by the leguminous hay; there is slight chance for trouble due to a lack of any of the inorganic elements necessary in nutrition.

The removal of the whole milk from the diet of the calf takes with it that growth essential known as fat-soluble A. In seeking another carrier of this vitamin we must ignore the other animal fats, as their use is impractical. In turning to the cereal grains, we find that most of them contain fat-soluble A in insufficient quantities, with the exception of flax, hemp, and millet seeds. We can adopt linseed meal as part of the grain mixture, as there is reason to believe that this by-product would retain the fat-soluble A. For additional quantities of this necessary substance we use the leafy portions of plants, and here again alfalfa hay forces itself into the foreground. The possibility of the animal's being able to store up a reserve supply of the

fat-soluble growth substance affords a means of tiding over that period during which it does not consume sufficient quantities of grain and hay to fill its demands for the accessory factor.

The second growth essential is so abundant in all of our every-day feeds that there is small reason to anticipate a shortage of it in any system of calf feeding. It is true that the capability of milk to furnish it in sufficient quantities is questioned; but here again the animal's ability to lay up a reserve supply will enable it to pass through a brief period until the character of its ration is such that the water-soluble B will be abundantly present. Cereal grains all carry it in ample quantities.

There is no apparent reason for making any fundamental alterations or adjustments in our calf feeding operations, but by adopting that part of the newer scientific knowledge which is of value, and which will have a recognized bearing on success in nutrition, we can profit by the revelations which science has made. We must continue to use the feeds available, or readily obtained, in prescribed quantities, but the recognition and understanding of the special efficiency of particular products, and a fuller comprehension of the demands of the growing organism, will lead us ultimately to a more judicious use of feeds in compounding rations.

Regarding the palatability of the ration little need be said, as it becomes difficult to conceive of any mixtures of feeding stuffs, which would constitute a "complete" ration in the modern sense of the word, and yet lack palatability.

One cannot traverse such a field of knowledge as that covered by this review without arousing some speculation as to the inner workings of the forces under observation. In this study of growth and nutrition, the impression grows that all the factors involved are somehow intimately related, and it is interesting to hazard a few guesses as to how these interrelations are connected up to form this close relationship. Surmises, when branded as such, do no particular harm; but they may serve the purpose of arousing interest enough to disprove or discredit them; and in so doing they serve a valuable purpose in that they may be instrumental in bringing further knowledge to light.

We recognize as the first factor in growth, the so-called growth impulse. Its nature is vague, but its power is undeniable. What is it? Is it not possible that it may in some way be connected with the ductless glands? May not the "stimulus" of "impulse" be due to an unidentified hormone? We know that the glands of internal secretion are able to function at a very early age in

utero, and for the brief period previous to that the fetus can rely on hormones from the parent. With the complex interrelationship and reciprocal activities of internally secreting organs now fairly well recognized, it does not seem difficult to attribute the growth stimulus to hormones.

The theory has been expressed of the relationship between certain amino acids and the active substances of endocrine organs. Knowing the importance of the role which certain of these organs play in growth, there is brought about a closer tie between nutrition and growth. It would appear that the diet must supply something essential for the proper functioning of the organs which secrete substances affecting growth. This may remove one of the so-called "internal factors" and bring it under direct control through the food supply.

There still remains the possibility that these unknown growth accessory substances, fat-soluble A and water-soluble B may be activators of the ductless glands. Since internal secretions seem to be unlimited, and the supposition is that the whole system is attuned and kept in balance by irritants and counter-irritants which are supplied in this way, is it not fair to assume that these unidentified substances have just such a function?

EXPERIMENTAL WORK.

One of the most perplexing problems confronting the dairy farmer who sells whole milk is that of feeding his calves. Since he disposes of his entire produce, there is no skim milk available, and it is out of the question to use large quantities of whole milk, as such a practice puts the cost of growing calves unreasonably high. The use of milk substitutes offers one solution, but entire satisfaction has not yet been obtained by this method. Skill is required in the preparation and feeding of the substitutes, and only in rare cases does this system bring entire success. Another means which suggests itself is to determine the smallest amount of milk necessary to successfully raise a calf.

The use of a minimum amount of milk for raising calves is a system of management which appeals to all producers who have a market for whole milk. When prices are attractive and the demand is good, there is a strong temptation to lose sight of the importance of keeping the young animals in a thrifty growing condition, and perhaps nothing will tend to retard the development of calves so

much as too early discontinuation of milk feeding. The wise dairy farmer will not let present profits lure him into a practice which would lower the future efficiency of his herd.

Preliminary Experiment - The original plan of the experiment was to wean calves at the age of three or four months and put them on a grain mixture and hay. The purpose was to find out if normal growth would result under such a system of handling. It was believed that the plan of raising calves would be simplified if a good grain mixture could be used after the age of four, or better still, three months is reached. This would be an improvement over the system usually followed, of continuing the use of calf meals or milk substitutes up to the age of six months. If this trial proved successful, the idea was to continue the work by using younger animals, and by this practice to determine the earliest age at which the calf could be safely weaned.

Five pure-bred heifer calves (three Holsteins and two Ayrshires) of the University of Missouri herd were used in this preliminary trial. One of the Holsteins was weaned at five months, one of the Ayrshires at four months, and the others at three months of age. The milk

allowance was gradually reduced and the weaning completed in ten days to two weeks. At the time this change started the calves were taking quite a bit of grain and alfalfa hay.

A simple grain mixture, one which could be easily prepared on the farm, was selected. It was made up of corn chop two parts and linseed meal one part. The calves were fed this mixture and as much alfalfa hay as they would eat. All feed was weighed to them and rejected feed weighed back. The animals were weighed at the end of each ten day period and measured every thirty days.

Table 1 summarizes the weight records and gains made by these five calves. The daily gains vary from 1.35 lbs. to 1.16 lbs. a day. In the case of calf No. 328, which made the minimum daily gains, the grain and hay fed were limited to $3\frac{1}{2}$ lbs. each. This may account for the failure of this animal to make as satisfactory gains as the others.

Parallel columns in Table 2 give a comparison of the actual weights with the normal weights of the three calves which were weaned at three months. These weights were taken at ten day intervals.

No difficulty was experienced in getting the calves to take sufficient quantities of the grain mixture and hay, and their growth compared very favorably with

the normal. The health of the animals was excellent throughout the trial and the results secured were entirely satisfactory.

Outline of the Main Experiment.

The success of the preliminary trials warranted a change in the original plan, and it was decided to wean the animals at about two months of age. Grade calves were bought for use in this work. The calves were secured when young, in order that their early growth could be controlled and kept up to the normal. The object was to have them in a thrifty condition and as near normal in size as possible at the beginning of the trial. No record was kept of the feed consumed during the first two months, but they received the usual herd care and feed. They were fed whole milk until from two to three weeks old; then changed gradually to skim milk. At the same time they were offered grain, and alfalfa hay was always available in a small feed rack.

Object of the Experiment - The object of the experiment reported here was to determine whether or not calves weaned at the age of about sixty days would continue to grow at the normal rate on grain and hay. It was not the purpose to see if the calves could be kept alive on a minimum quantity of milk up to sixty days, but to find out if calves which had grown normally up to that age

could then be changed onto a ration of grain and hay without checking their growth materially.

By pursuing this method of determining the earliest age at which calves can be safely weaned and the minimum amount of milk needed to bring them to that age in normal condition, it would be possible to establish a system of calf feeding involving the use of a minimum quantity of milk in combination with a simple grain mixture and hay rather than expensive or impractical milk substitutes.

Feeding the animals in groups afforded an opportunity for comparing different grain mixtures.

Blood meal or blood flour is frequently recommended as part of the grain ration for calves up to the age of six months. It is expensive and sometimes hard to obtain. It was fed in the grain mixture of one group to determine if its nutritional value was commensurate with its cost.

Alfalfa hay has been used in many successful calf feeding trials, and apparently has some special value in feeding young animals. To determine if possible the value of different kinds of hay in the calf ration, one group was fed timothy hay; the others alfalfa hay.

Animals Used - Six grade Holstein calves and three grade Jerseys were secured from dairymen in the vicinity of Columbia to be used for this experiment. The inheritance factor was partly annulled by the fact that all of the Holstein calves were sired by the same bull, and two of the Jerseys were twins. The calves were good specimens of their respective breeds. They were divided into three groups of two Holsteins and one Jersey each. Detailed statistics of the animals are given in Table 3.

Rations Used - The object in view in selecting the basal grain mixture was to adopt one simple enough to be used in ordinary farm practice, and yet sufficiently complex to embody the essential factors for a complete ration as now understood. It was also desired to have the ration supply protein and energy in about the same proportions as milk.

The grain mixture chosen was made up of ground corn 40 parts, wheat bran 10 parts, and linseed meal 10 parts by weight. This was designated as Calf Mixture A.

For the purpose of testing the efficiency of blood meal in the ration, and also as a means of substituting part of the vegetable protein with animal protein, a second mixture was fed to some of the calves. This was

called Calf Mixture B, and was made up of ground corn 40 parts, wheat bran 10 parts, linseed meal 5 parts, and blood meal 5 parts by weight.

Alfalfa hay was fed to two of the groups of calves, and timothy hay to the third group.

Calf Mixture A furnishes protein from three vegetable sources, which is further supplemented by the protein of the alfalfa hay. This combination would seem to supply a protein mixture of sufficient variety to meet the demands of the growing animal. This grain mixture has the common fault of all such mixtures; that is, a shortage of inorganic matter, but this deficiency is overcome by the alfalfa hay fed in connection with it. Alfalfa hay affords a sufficient supply of fat-soluble A, which is also present in the linseed meal and to a limited extent in the corn and bran. The water-soluble growth accessory is supplied abundantly by both the grain and hay.

Calf Mixture B has the additional value of more complex protein mixture, due to the addition of the animal protein of the blood meal. This would tend to increase the lysine content of the ration, as blood meal is richer in this amino acid than the linseed meal which it replaces. There may be some loss of palatability by the use of blood meal because of its disagreeable odor.

Corn supplies energy in its cheapest form, bran furnishes some protein and adds bulk, while the linseed meal carries more protein and its mild laxative properties add to its value in the ration.

Methods of Feeding - All feed was weighed to the calves and any portion rejected was carefully weighed back. Chopped hay was used in order to insure a more thorough and uniform consumption of stem and leaf. This also facilitated the work of weighing. No effort was made to limit the amount of feed, except that a maximum of 5 lbs. per day of grain was established. This was done largely to force the calves to consume more hay. The animals were fed according to their appetites, the idea being to give them as much feed as they cared for.

Lot I. - This group of three calves was weaned at about sixty days and then fed Calf Mixture A and alfalfa hay.

Lot II. - This group of three calves was weaned at about sixty days and then fed Calf Mixture B and alfalfa hay.

Lot III. - This group of three calves was weaned at about sixty days. Two of them were fed Calf Mixture A and the other Calf Mixture B. Alfalfa hay was fed until

they were ninety days old and then they received timothy hay in addition to their grain.

Water and salt were available at all times when the calves were out for exercise, which was throughout the day and during the night when the weather permitted. During most of the experimental period they were kept up only at feeding time, as the weather was unusually mild the greater part of the winter.

Housing - The animals were kept at the dairy barn with the herd calves until ready to put on experiment. At that time they were moved to an experimental barn. They were kept in individual stalls, with no possibility of getting any feed beside that which was put in their mangers. They were bedded with wood shavings. The barn was provided with windows along the north and south sides and a door at both the east and west ends. This afforded plenty of light and facilities for ventilation. The calves were allowed to exercise in a lot adjoining the barn on the south and west sides, and were kept out of doors as much of the time as the weather would permit. There was a water tank and salt box in this lot.

Weighing and Measuring - The calves were weighed when put on experiment, and at regular ten-day intervals thereafter until the trial was completed. Each thirty days the weights were taken for three successive days and an average of these three weights used. This afforded some check on the daily fluctuations.

The standard adopted for determining skeletal growth was the height at withers. Height measurements were taken at the beginning of the experiment and at regular thirty-day intervals thereafter. The rate of growth is slow, and it was deemed unnecessary to measure the height more often than once every thirty days. Observation has shown that an animal at rest tends to settle at the withers, and measurements taken immediately after the animal has been moving about are usually greater than those taken after it has been at rest for some time. To overcome this variation, three measurements were taken in each case and the animal was moved about before each one. An average of the three was used as the height measurement.

Discussion of Data.

Growth - The object of this experiment was to determine if calves could be weaned at two months of age and then fed grain and hay without materially retarding their growth. In order to know whether or not these trials were successful, it was necessary to have some standard of comparison; since no check animals were used in the experiment. Individuality is a prominent factor in feeding trials, and for this reason the use of one or two check animals in work of this kind is open to criticism. There is no means of telling whether or not the individuals used to compare with the experimental animals are normal in all respects and capable of making characteristic gains in weight and size for their species. The breed factor also enters into this problem and would necessitate the use of several check animals.

For these reasons all comparisons are made to the figures for normal growth of dairy cattle, as determined by weights and measurements taken on a large number of animals at the Missouri Experiment Station. Because these figures are averages of those obtained from many animals, the factor of individuality is eliminated. Table 4 was adopted from unpublished data of the above experiment

station, and embodies the figures used in the tables and text of this thesis wherever normal growth is referred to.

The periods listed in the various tables are of ten days duration between weighings. The weight and measurement shown on a line with the number of the period are the weight and measurement at the beginning of that period.

Lot I. - Tables 5, 6, and 7 give detailed information regarding weights and measurements of the three animals in this lot.

Calf H-1, put on experiment at the age of 69 days, weighed 177 lbs., or 104.1% normal weight for that age. In 110 days he gained 180 lbs., an average of 1.64 lbs. a day. This was the best average daily gain.

H-4 started at the same age and gained 179 lbs. in 120 days, an average of 1.49 lbs. a day. The 179 lbs. gained was 93.7% of the normal increase in weight for that period. This calf remained above normal in height during the entire trial.

The Jersey calf of this lot, J-2, increased 153 lbs. in weight in the 120 days on experiment, which was 98.1% of the normal increase for that period. It also remained above normal in height. The average daily gain was 1.28 lbs. Undoubtedly this calf would have made larger daily gains, but during the seventh

period he was badly constipated and off feed. The administration of several doses of oil and an injection of warm water finally relieved the condition. The calves in Lot III. all contracted pneumonia during the latter part of January, and at about the same time this calf was again off feed, and it is now believed that he had a light attack of pneumonia; although he showed none of the external symptoms exhibited by the other sick animals.

A summary of the growth figures on this lot of calves is shown in Table 14. They made an average increase in weight of 171 lbs., and an average increase in height of 16.66 cm. This amounted to 97.8% and 91.96% respectively of the normal increases. The average daily gains in weight ranged from 1.64 lbs. to 1.28 lbs.

Lot II. - Detailed information on the growth of this group of three calves is given in Tables 8, 9, and 10.

Calf H-2 weighed 175 lbs. at the age of 62 days, and made a gain of 153 lbs. in 120 days, which was only 79.7% of the normal gain for that period. His gain of 16.33 cm. in height was 86.95% of the normal. This calf developed a severe case of scours during the second period of the experiment, which checked his early growth. This may have been due to the change to green leafy alfalfa hay, as previously he had been receiving an inferior quality of hay. The daily gain of 1.28 lbs. is

the lowest for this lot.

H-3 was slightly older than the other calves when started, and she was somewhat below normal size at the beginning. Her increase of 190 lbs. in weight was 99.5% of the normal increase for the period of 120 days; and 18.44 cm. gain in height was 101.1% of the normal. In average daily gain she was high for this lot, and ranked second among all the calves, with 1.58 lbs. She was the only calf which made more than normal increase in height during the experiment.

The Jersey calf in this lot, J-3, started and finished well above normal. Although he scoured badly during the first and second periods, due probably to the change to green leafy alfalfa hay, he made a complete recovery. His increase of 173 lbs. in weight was 110.9% of normal, which is highest of all the animals. He also made 96.37% of the normal increase in height.

Lot II. as a whole averaged 173 lbs. increase in weight and 17.61 cm. increase in height, which are 96.7% and 94.81% respectively of the normal growth figures for the period of the trial. The figures for these animals are summarized in Table 14. The average daily gains in weight ranged from 1.53 lbs. to 1.28 lbs. The fact that two animals in this lot were troubled with scours during the early part of the trial might reflect discredit on the blood meal in their grain mixture, but there is no

reason to believe that the trouble was due to the blood meal. However, it was observed that large numbers of flies were attracted by the odor and as they were rendered sluggish by the cold weather, they may have been eaten by the calves with the grain. This trouble was only experienced during the early periods of the experiment. There is more reason to believe that the digestive disturbances were due to the feeding of the bright green leafy alfalfa hay after the calves had become accustomed to an inferior quality of brown hay.

Lot III. - The individual growth records for the animals in this lot are given in detail in Tables 11, 12, and 13.

Calf H-5 of this lot started at the age of 62 days, weighing 175 lbs., 109.4% of normal. At the end of the trial this calf weighed 310 lbs. and was 88.1% normal. His total increase in weight was 135 lbs., which is 70.3% of the normal increase, and he gained 14.76 cm. in height, or 78.59% of the normal increment for the period. Timothy hay feeding began at the end of the third period, and shortly after there was a gradual decline in the rate of growth and the animal soon dropped behind the normal figures. During the latter part of the eleventh period this calf was stricken with pneumonia. The nature of the

affliction was not correctly diagnosed by the veterinarians at the time, but it was deemed advisable to make a change in the ration of this animal in an effort to determine if its condition was due to nutritional causes. This was done, and the animal made a complete recovery; but there is no reason to believe that this is attributable to the change in the diet, as one of the other animals similarly afflicted recovered without change in food.

H-6 was rather a poor feeder from the start, and statistics in Table 12 show that he was undersized at the time the experiment started. During the trial of 120 days he gained 136 lbs. in weight and 15.38 cm. in height, 71.4% and 81.38% respectively of the normal for that time. Timothy hay feeding began at the end of the third period, and this animal apparently maintained its proportion of normal weight fairly well, but failed to do so in skeletal growth as indicated by height at withers. Pneumonia struck this calf on the same day as the one previously mentioned, which was in the tenth period of the trial for this animal. It was thought best to permit this calf to die in order to determine if possible the nature of the malady, and no effort was made to bring about a recovery. The calf became emaciated and weak and refused to eat for almost a week, but it then began to consume its original ration and effected a rapid recovery. No change in food was made and no medicine administered.

J-4, the Jersey calf in this group, began the trial at the age of 60 days, weighing 123 lbs., which was 117.1% of normal weight for that age. During the 120 days of the experiment he gained 127 lbs. in weight and 15.83 cm. in height at withers, or 81.9% and 83.32% respectively of the normal increases for that length of time. For five periods he maintained his relation to the normal weight fairly constant, but apparently at that time the effects of the timothy hay feeding were beginning to be felt, and there was a rapid decline. It was during the eighth period that the epidemic of pneumonia struck the calves, and this animal was just a little over four months old. It suffered severely from the disease, and a change of ration was made to assist it to recover. Milk was fed for a couple of days, and alfalfa substituted for the timothy. The animal apparently made a complete recovery, as at the end of the trial it was making fairly satisfactory gains in weight. The severity of its affliction may account partly for its low average daily gain in weight of 1.06 lbs., which was the smallest for all calves.

Lot III. as a whole, as shown by Table 14, made an average increase in weight of 133 lbs., or 74.5% of the normal increase for the period. The average increase in height was 15.32 cm., or 81.1% of normal. It is evident that this lot fell far behind the alfalfa hay groups. The two factors responsible for this apparently are the timothy hay and pneumonia.

Food Consumed - Some interesting comparisons are afforded by the feeding records of the individuals and groups. These records also show the relative economy of the grain mixtures used.

The calves were fed liberally at all times in order to give them every opportunity to grow. The only limit placed on their ration was a maximum of 5 lbs. of grain a day, which was established in order to insure their consuming a sufficient quantity of hay. Feeding grain beyond this limit seemed wasteful, as calves of this age should be able to utilize hay in considerable quantities.

The tables of digestible crude protein and net energy value of the feeding stuffs are calculated by using the figures shown in Table VII. in the appendix of the book entitled "Nutrition of Farm Animals" by H. P. Armsby,⁶ pages 715 to 721, inclusive.

Lot I. - Detailed information on the feed consumed and periodic gains in weight by the animals in this lot are set forth in Tables 15, 16, and 17.

Animal H-1 was an excellent feeder and reached the maximum of 5 lbs. of grain daily at the beginning of the seventh period. For the entire trial he averaged a gain of one pound on less than half a pound of milk and approximately $2\frac{1}{2}$ lbs. each of grain and hay.

H-4 consumed about 500 lbs. each of grain and hay during the 120 days of the trial, and averaged one pound of gain for each 0.715 lb. of milk, 2.859 lbs. grain and 2.703 lbs. of hay eaten.

J-2 shows a decided break in his feed record during the seventh period. At that time the calf was badly constipated and the administration of several doses of oil was found necessary to relieve the condition. Later on, during the eleventh period, he is believed to have suffered from a light attack of pneumonia, as the calves in Lot III. were sick at that time, but this animal did not display the outward symptoms that were so apparent in the others.

In spite of these setbacks he made very economical use of his food and increased his weight one pound for each 0.902 lbs. of milk, 2.778 lbs. of grain and 2.268 lbs. of hay.

Summary of food and nutrients consumed per pound of gain for this lot is shown in Table 24. Milk 0.687 lb., grain 2.742 lbs., and hay 2.490 lbs. produced a pound of gain on these calves. This quantity of feed contained 0.6187 lb. digestible crude protein and 3.1641 therms of net energy.

Lot II. - Tables 18, 19, and 20 give detailed information on the feed consumed by the animals in this lot.

Calf H-2 got off to a poor start because it scoured badly, and the milk feeding was prolonged somewhat for this reason. After this initial trouble was overcome the animal progressed well and finished the trial in excellent condition. Approximately three-fourths pound of milk, three pounds of grain and two and two-thirds pound of hay were required for each pound of gain.

H-3 proved to be a good feeder from the start, and aside from a slight check in the eleventh period, showed a constant increase in feed and nutrients consumed. This setback may also have been due to a light case of pneumonia; although this cannot be stated with certainty. This animal made much more economical use of its feed in producing gains in weight than H-2.

The Jersey calf J-3 also experienced trouble with scours at the beginning of the experiment, and received additional milk in order to overcome the trouble. He proved to be rather a delicate eater at first, but during the latter half of the trial made remarkable gains, averaging close to two pounds per day. He reached the maximum grain allowance at the end of the tenth period, and toward the close of the experiment was eating more than $5\frac{1}{2}$ lbs. of hay daily. A pound of milk, two and one-half pounds of

grain, and slightly over two pounds of hay were consumed for each pound of gain.

The figures in Table 24 show that Lot II. averaged 0.865 lb. of milk, 2.709 lbs. grain and 2.392 lbs. of hay for each pound of gain. This amount of feed contained 0.7019 lbs. digestible crude protein and 3.0804 therms of net energy.

Lot III. - Details of feed and nutrients consumed by this group of animals by periods are contained in Tables 21, 22, and 23.

Calf H-5 received the grain mixture A. Alfalfa hay was fed for the first thirty days of the experiment and it was then substituted with timothy hay. During the eleventh period, while the calf was sick, a small quantity of milk was fed, and alfalfa hay used instead of timothy. The hay was changed back as soon as the animal had regained its appetite. To make one pound of gain this calf used 0.985 lb. milk, 3.485 lbs. grain, and 2.726 lbs. of hay.

H-6 was rather a delicate eater at the outset, and never reached the maximum in grain consumption. After thirty days on alfalfa hay he was switched to timothy, but this did not retard his growth apparently. He received the grain mixture B. The decided check during the tenth period was due to pneumonia. Despite this sudden check he gained one pound in weight on 1.140 lbs. milk, 2.994 lbs. grain, and 2.717 lbs. hay.

J-4 was the first calf to contract pneumonia, and seemed to suffer more than the other two calves, which were older. He received Calf Mixture A throughout the trial, and at the age of ninety days was changed from alfalfa to timothy hay. The feeding of a small amount of milk and alfalfa hay during the eighth period may have helped to bring about his recovery from pneumonia, but this cannot be said with certainty. To make one pound of gain in weight, he consumed 1.117 lbs. of milk, 3.553 lbs. of grain, and 2.406 lbs. of hay. The low daily gain in weight makes the average food consumption high for each pound of gain. After recovering from pneumonia he reached the maximum grain allowance at the end of the ninth period, and when the trial closed he was consuming approximately $4\frac{1}{2}$ lbs. of timothy hay in addition to the grain.

Lot III., the timothy eaters, as a whole, used 1.081 lbs. of milk, 3.344 lbs. grain, and 2.616 lbs. of hay for each pound increase in weight. In every respect this is less economical use of feed than for the alfalfa groups. However, in nutrients consumed, the total digestible protein figure, 0.5952 lb. a pound of gain is lower than for Lots I. and II.; but 3.6902 therms of energy for the timothy group tops that of either of the alfalfa lots. The low protein content of timothy hay, combined with its lack of palatability and the inability of the animals to consume greater quantities, accounts for these differences.

Besides this, the losses in weight occasioned by sickness reduced the average daily gains of this lot of calves somewhat.

General Summary - The results obtained are shown graphically for Lots I., II., and III. in Figures 1, 2, and 3, respectively, and a summary of the three lots in Figure 4. These graphs show comparisons on a percentage basis of the actual growth (as indicated by increase in weight and height at withers) with normal growth, the normal being represented by 100 per cent. It will be observed that without exception there is a downward tendency in the weight curve during the first feeding periods. This was to be expected, as the change from milk feeding throws rather a severe strain on the undeveloped digestive organs of the young calf, and besides it takes some time for the animal to become adjusted to the change. During this period there is a tendency for the animals to be constantly on the lookout for milk, and until this restlessness is overcome they do not seem to prosper on the new feed.

Two methods of weaning were tried. One plan was to reduce the quantity of milk one half, and at the end of ten days to discontinue milk feeding entirely. This was

used in the cases of H-1 and H-3, but the latter calf developed scours and was given more milk. The other calves were weaned by reducing the allowance to one half for ten days and then further reducing it by two pounds at short intervals. Neither system appears to have any advantage over the other, as one calf also developed scours under the second plan.

Figures 1 and 2 also show that after the initial setback, the animals in Lots I. and II. maintained a very favorable parallel with the normal line, with a gradual rise toward the latter end of the experiment. The most notable exception is calf J-3, which was off feed twice, as previously explained. The composite curves for these two lots as shown in Figure 4 compare very well with the normal.

In contrast with the animals in the first two lots, Figure 3 shows the weight curves of the three calves in Lot III., which received timothy hay when about ninety days old. Each one of these curves shows a decline from start to finish, with a decided dip during that period when the calves were sick. It is to be regretted that they were stricken in this manner, as this has a tendency to make the figures abnormal. However, there is every indication that the trend was downward, and even if they had not suffered from pneumonia, it is quite safe to assume that they would have finished well behind the other calves fed on alfalfa

hay. J-4 seemed to be more severely affected by the disease than the Holstein calves, and showed a much greater decline in weight, which may also account for the upward trend of his weight curve toward the latter end. The same seems to be true of the height measurements on this calf. The composite curve in Figure 4 for this lot runs almost parallel with the normal for about fifty days, and then there is a decided drop which continues almost to the end of the trial; the slight rise at the end indicating recovery from pneumonia.

The height curves almost all show a slight tendency to drop down. In Lot I. this is not very marked except in the case of J-2. In Lot II., after the initial drop, the curves of the Holstein calves trend upward; while that of the Jersey parallels the normal for sixty days. As was to be expected in Lot III., all height curves show a decided and constant downward tendency, with the exception of the last period for the Jersey calf. Figure 4 brings out these facts more clearly, and the Jersey calf in Lot I. brings the curve downward. The latter part of the Lot II. curve bends upward; while Lot III. crosses the normal line and continues to drop.

This striking contrast between the two groups fed alfalfa hay and the one fed timothy hay would indicate that the former is far more efficient as a calf feed. The calves in Lot III. were fed similar grain rations and

given the same care and attention as those in the other two lots, and it is safe to attribute the difference in growth to the greater efficacy of the alfalfa hay in inducing growth.

Another noteworthy fact brought out by this trial is that although all calves were equally exposed to the outbreak of pneumonia, only the three in the timothy hay lot developed decided symptoms of the disease. Two of the other calves were off feed at the same time, but neither one showed the outward signs displayed by the sick animals. The three animals in Lot III. all showed the effects of the disease within forty-eight hours. It was characterized by labored breathing, spasmodic jerking in the flanks, a dry cough, weak, listless condition, loss of appetite, and temperature of over 104 degrees.

All the animals on this experiment were housed in the same barn, and subject to the same conditions. Those which developed pneumonia were not in adjoining stalls, nor in any particular part of the barn, but were well distributed among the other calves.

It would appear that the animals in the other two lots were on a better plane of nutrition which enabled them to withstand the disease; or else there was something contained in the alfalfa hay which fortified them against the malady. The calves in Lot III. were not weak and

emaciated, nor in a condition which would be apt to cause them to fall prey to sickness. They were in far better condition than most of the calves on ordinary farms during the winter season, and the fact that they were very close to normal size would preclude the possibility that their vitality had been lowered and resistance decreased because of lack of proper nutrition. We still lack a suitable explanation for these facts.

A comparison of Lots I. and II. by the curves shown in Figure 4 fails to bring out any striking contrasts, and there is little to choose between them. Lot II. may appear to have a slight advantage in growth, but it must be borne in mind that this lot contained one older animal, and also that J-2 in Lot I. had two decided dips in his growth curves. The figures in Table 14 show how closely these two groups of animals average. Lot I. made 97.8% of its normal increase in weight; while Lot II. made 96.7%. On the other hand, Lot I. only shows 91.96% of its normal increase in height as compared with 94.81% for Lot II.

Lot III. does not compare favorably with either of the other two groups of calves in gains in weight or height. The graphic story of Figure 4 needs no comment. The three calves in Lot III. averaged only 74.5% of their normal increase in weight, and 81.1% of the normal gain in height; whereas both of the other lots averaged well above ninety per cent in every case.

Table 25 furnishes a comparison of the total amounts of feed and nutrients consumed by the various lots. The difference between the total feed used by Lot I. and Lot II. is very slight, and corresponds very well to the difference in growth of these two lots as indicated in Figure 4. The blood meal in calf mixture B brought up the total pounds of digestible crude protein of Lot II. These animals consumed 360.26 lbs. of digestible crude protein as against 317.92 lbs. for Lot I. Lot I. had 1620.32 therms of net energy as contrasted with 1580.98 therms for Lot II. The average daily gains for these lots were 1.47 and 1.43 lbs., respectively. To make one pound of gain in weight, Lot I. consumed 0.687 lb. milk, 2.742 lbs. grain and 2.490 lbs. hay; Lot II., 0.865 lb. milk, 2.709 lbs. grain, and 2.392 lbs. hay. For one pound increase in weight 0.6187 lb. digestible crude protein and 3.1641 therms of net energy were used by Lot I., and 0.7019 lb. protein and 3.0804 therms of energy by Lot II.

Apparently the more economical gains were made by Lot I., especially in view of the fact that the blood meal increased the cost of the grain mixture fed to Lot II.

In comparing the alfalfa hay groups with the timothy hay calves, it is apparent at once that the latter made decidedly lower average daily gains. The total consumption of hay by the timothy group was decidedly less than that of the two alfalfa hay lots. There was naturally

a much lower quantity of digestible crude protein in the feed eaten by the calves in Lot III.

The failure of the animals in Lot III. to make better growth may be owing to their failure to consume more of the timothy hay. This is perhaps due to its lack of palatability.

Lot III. fell somewhat behind the other two lots in total grain consumed, and ate considerably less hay. This latter fact, combined with the low protein content of timothy, brought down the total consumption of digestible crude protein for the lot; although the energy consumed compares favorably with that of the alfalfa hay lots, when size is taken into consideration. The average consumption of digestible crude protein per pound of gain is 0.5952 lb. for Lot III. and 0.6187 for Lot I. Low daily gains for the timothy calves make the figures high for the average grain and hay eaten for each pound of gain in weight.

Influence of Breed - The results obtained in this trial fail to indicate any decided difference between the Jersey and Holstein calves, either in comparative rate of growth, amount of feed consumed, or utilization of feed. In Lot I. the Jersey calf is very close to the average for food and nutrients consumed per pound of gain, and in Lot II., J-3 is somewhat below the average of the lot.

J-2 failed to gain as much as the Holstein calves in Lot I., but this may be accounted for by reasons already given. In Lot II., calf J-3 made an average daily gain of 1.44 lbs.; while the average for the entire group was 1.43 lbs. While J-4 gained 0.07 lb. less per day than the Holsteins in Lot III., it made a higher percentage of its normal increase in both weight and height during the experiment.

In percentage of normal increase, a Jersey ranked first for all calves. This was J-3, with 110.9%. Holsteins ranked second and third, and another Jersey fourth. H-3, a Holstein, made the greatest percentage of normal increase in height, with 101.1%. A Jersey ranked second, with Holsteins third and fourth, and another Jersey fifth.

These figures leave little to choose between these breeds.

Comparative Cost of Raising Calves - There is a decided saving on feed cost of calves reared according to the system employed in this experiment as compared with the practice of feeding skim milk for a six month period. Any figures or estimates based on present feed costs are necessarily of only temporary value. Below is a comparison of average feed consumed by two groups of calves during a period of 120 days, beginning at the age of two months:

	Skim Milk	Grain	Alf. Hay
Skim Milk Calves	1808 lbs.	178 lbs.	255 lbs.
Calves in Lot II.	138 "	463 "	409 "
Difference	1670 "	285 "	154 "

Calves used in this experiment consumed 1670 lbs. less of skim milk and 285 lbs. and 154 lbs. more of grain and alfalfa hay, respectively. Skim milk today has a value of 18 cts. a gallon here, and the grain mixture fed is worth 3 cts. a pound and alfalfa hay 1.5 cts. a pound. On a basis of these values, a calf could be fed according to the system outlined in this experiment at a saving of about \$25.00 for the four months. This figure will fluctuate with feed and skim milk values, but there is no mistaking the economy of the practice of weaning at sixty days.

CONCLUSIONS.

1. Dairy calves in good thrifty condition can be weaned at the age of sixty to seventy days and will continue to grow and develop at approximately the normal rate when fed on a suitable grain mixture and alfalfa hay.
2. More satisfactory results are obtained when alfalfa hay is used to supplement the grain in the ration than with timothy hay. The animals consume more of the alfalfa than timothy, make better gains in weight and height, and appear to be more vigorous and resistant.
3. Blood meal in the grain mixture fed to calves more than two months old has no pronounced nutritional value, and its high cost does not warrant its use for calves of this age.
4. A grain mixture of ground corn, wheat bran, and linseed meal, in quantities prescribed in this experiment, fed in conjunction with alfalfa hay, apparently supplies all the requirements for normal growth of calves from two to six months old.

5. Breed has no influence on the results obtained by feeding according to the plan outlined in this experiment.
6. There is a sharp decline in weight immediately after the milk is removed from the ration, but this is regained when the calf becomes accustomed to the change in feed.
7. Weaning at the age of sixty days has a more lasting effect in checking skeletal growth than the increase in weight. The latter is more pronounced at the start but the recovery is more prompt; while the effect of checking the growth in height is more lasting, although not so severe.
8. Raising calves by weaning at sixty days of age and subsequently feeding them on grain and alfalfa hay is more economical than feeding skim milk, grain and hay until the animals are six months old. This is true only where there is a market for skim milk.

TABLE 1.

WEIGHT RECORDS OF CALVES USED IN PRELIMINARY
EXPERIMENT.

No.	Age at Weaning Mo.	Days Fed	Initial Weight lbs.	Final Weight lbs.	Total Gain lbs.	Daily Gain lbs.	Per cent of Normal Weight
281	5	30	343	380	37	1.23	105.0
327	4	60	227	306	79	1.32	104.4
282	3	90	210	322	112	1.24	87.0
283	3	90	220	342	122	1.35	92.7
328	3	90	205	310	105	1.16	101.6

TABLE 2.

COMPARISON OF ACTUAL WEIGHTS WITH NORMAL WEIGHTS
OF CALVES IN PRELIMINARY TRIAL.

Animal	282		283		328	
Period	Actual Weight	Normal Weight	Actual Weight	Normal Weight	Actual Weight	Normal Weight
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1	210	226	220	224	205	195
2	226	243	244	240	217	207
3	241	260	255	258	240	220
4	250	278	253	276	244	233
5	261	296	268	294	248	246
6	268	312	279	310	260	258
7	280	328	290	326	265	271
8	295	344	302	342	281	284
9	309	357	312	356	285	295
Final	322	370	342	369	310	305

TABLE 3.

DETAILED DESCRIPTION OF CALVES USED ON EXPERIMENT.

Lot	No.	Breed	Sex	Age at Beginning days	Days Fed days
I.	H-1	Holstein	Bull	69	110
	H-4	"	Heifer	69	120
	J-2	Jersey	Bull	65	120
II.	H-2	Holstein	Bull	62	120
	H-3	"	Heifer	71	120
	J-3	Jersey	Bull	65	120
III.	H-5	Holstein	Bull	62	120
	H-6	"	"	60	120
	J-4	Jersey	"	60	120

TABLE 4.

NORMAL WEIGHTS AND MEASUREMENTS FOR DAIRY CALVES.

Age months	HOLSTEIN		JERSEY	
	Weight lbs.	Height at Withers cm.	Weight lbs.	Height at Withers cm.
Birth	88	71.8	53	66.1
1	121	76.8	76	70.3
2	157	82.0	105	74.7
3	200	86.8	140	79.3
4	249	92.0	174	83.9
5	302	96.5	222	89.3
6	349	100.9	260	93.7
7	389	104.0	302	96.8
8	425	107.1	340	99.8

TABLE 5.

WEIGHT AND HEIGHT RECORDS.

CALF H-1.

Age at Beginning, 69 days.				Duration of Trial, 110 days.			
10 day Period	Actual Weight	Normal Weight	% of N. Weight	Actual Height	Normal Height	% of N. Height	Gain in Weight.
	lbs.	lbs.	Per Ct.	cm.	cm.	Per ct.	lbs.
1	177	170	104.1	83.25	83.44	99.77	6
2	183	184	99.4				7
3	190	198	96.0				12
4	202	214	94.4	88.89	88.33	100.63	20
5	222	230	96.5				18
6	240	247	97.2				19
7	259	265	97.7	93.78	93.35	100.46	15
8	274	283	96.8				19
9	293	300	97.7				27
10	320	316	101.3	97.78	97.85	99.93	14
11	334	332	100.6				23
Final	357	347	102.9	99.83	100.75	99.09	
Total In- crease	180	177	101.7	16.58	17.31	95.78	180
Av. da. Gain	1.64	1.61		0.150	0.157		

TABLE 6.
WEIGHT AND HEIGHT RECORDS.

CALF H-4.

Age at Beginning, 69 days.				Duration of Trial, 120 days.			
10 day Period	Actual Weight	Normal Weight	% of N. Weight	Actual Height	Normal Height	% of N. Height	Gain in Weight.
	lbs.	lbs.	Per ct.	cm.	cm.	Per ct.	lbs.
1	180	170	105.8	85.47	83.44	102.43	4
2	184	184	100.0				16
3	200	198	101.0				14
4	214	214	100.0	89.71	88.33	101.56	16
5	230	230	100.0				15
6	245	247	99.2				10
7	255	265	96.2	93.97	93.35	100.66	20
8	275	283	97.2				15
9	290	300	96.7				18
10	308	316	97.5	98.50	97.85	100.66	14
11	322	332	97.0				20
12	342	347	98.6				17
Final	359	361	99.4	102.25	101.80	100.44	
Total In- crease	179	191	93.7	16.78	18.36	91.40	179
Av. da. Gain	1.49	1.59		0.140	0.153		

TABLE 7.
WEIGHT AND HEIGHT RECORDS.

CALF J-2

Age at Beginning, 65 days.				Duration of Trial, 120 days.			
10 day Period	Actual Weight	Normal Weight	% of N. Weight	Actual Height	Normal Height	% of N. Height	Gain in Weight.
	lbs.	lbs.	Per ct.	cm.	cm.	Per ct.	lbs.
1	137	111	123.4	79.54	75.45	105.42	9
2	146	123	118.7				18
3	164	135	121.5				3
4	167	146	114.4	84.50	80.05	105.56	18
5	185	157	117.8				12
6	197	168	117.3				17
7	214	182	117.6	88.50	84.80	104.36	-15
8	199	198	100.5				30
9	229	214	107.0				11
10	240	229	104.8	92.44	90.05	102.65	20
11	260	242	107.4				-1
12	259	255	101.6				31
Final	290	267	108.6	96.17	94.20	102.09	
Total In- crease	153	156	98.1	16.63	18.75	88.69	153
Av. da. Gain	1.28	1.30		0.139	0.156		

TABLE 8.

WEIGHT AND HEIGHT RECORDS.

CALF H-2.

Age at Beginning, 62 days.				Duration of Trial, 120 days.			
10 day Period	Actual Weight	Normal Weight	% of N. Weight	Actual Height	Normal Height	% of N. Height	Gain in Weight.
	lbs.	lbs.	Per ct.	cm.	cm.	Per ct.	lbs.
1	175	160	109.4	84.17	82.32	102.25	9
2	184	174	105.7				-2
3	182	188	96.8				6
4	188	203	92.6	87.50	87.14	100.41	3
5	191	219	87.2				18
6	209	235	88.9				23
7	232	253	91.7	91.11	92.30	98.71	9
8	241	271	88.9				19
9	260	289	90.0				15
10	275	305	90.2	95.33	96.80	98.48	15
11	290	321	90.3				20
12	310	337	92.0				18
Final	328	352	93.2	100.50	101.10	99.41	
Total In- crease	153	192	79.7	16.33	18.78	86.95	153
Av. da. Gain	1.28	1.60		0.136	0.157		

TABLE 9.
WEIGHT AND HEIGHT RECORDS.

CALF H-3.

Age at Beginning, 71 days.				Duration of Trial, 120 days.			
10 day Period	Actual Weight	Normal Weight	% of N. Weight	Actual Height	Normal Height	% of N. Height	Gain in Weight.
	lbs.	lbs.	Per ct.	cm.	cm.	Per ct.	lbs.
1	157	172	91.3	83.89	83.76	100.16	9
2	166	186	89.2				19
3	185	202	91.6				11
4	196	218	89.9	89.05	88.67	100.43	16
5	212	234	90.6				23
6	235	251	93.6				10
7	245	269	91.1	92.83	93.65	99.12	16
8	261	287	90.9				22
9	283	304	93.1				14
10	297	320	92.8	97.72	98.15	99.56	18
11	315	336	93.7				6
12	321	350	91.7				26
Final	347	363	95.6	102.33	102.00	100.32	
Total In- crease	190	191	99.5	18.44	18.24	101.10	190
Av. da. Gain	1.58	1.59		0.154	0.152		

TABLE 10.
WEIGHT AND HEIGHT RECORDS.

CALF J-3.

Age at Beginning, 65 days.				Duration of Trial, 120 days.			
10 day Period	Actual Weight	Normal Weight	% of N. Weight	Actual Height	Normal Height	% of N. Height	Gain in Weight.
	lbs.	lbs.	Per ct.	cm.	cm.	Per ct.	lbs.
1	130	111	117.1	77.93	75.45	103.29	-2
2	128	123	104.1				16
3	144	135	106.7				6
4	150	146	102.7	82.05	80.05	102.50	14
5	164	157	104.5				14
6	178	168	106.0				8
7	186	182	102.2	86.47	84.80	101.97	18
8	204	198	103.0				14
9	218	214	101.8				24
10	242	229	105.7	91.78	90.05	101.92	17
11	259	242	107.0				21
12	280	255	109.8				23
Final	303	267	113.5	96.00	94.20	101.91	
Total In- crease	173	156	110.9	18.07	18.75	96.37	173
Av. da. Gain	1.44	1.30		0.150	0.156		

TABLE 11.

WEIGHT AND HEIGHT RECORDS.

CALF H-5.

Age at Beginning, 62 days.				Duration of Trial, 120 days.			
10 day Period	Actual Weight	Normal Weight	% of N. Weight	Actual Height	Normal Height	% of N. Height	Gain in Weight.
	lbs.	lbs.	Per ct.	cm.	cm.	Per ct.	lbs.
1	175	160	109.4	84.07	82.32	102.12	11
2	186	174	106.9				16
3	202	188	107.4				13
4	215	203	105.9	88.00	87.14	100.99	18
5	233	219	106.4				19
6	252	235	107.2				8
7	260	253	102.8	91.64	92.30	99.28	8
8	268	271	98.9				10
9	278	289	96.2				10
10	288	305	94.4	95.78	96.80	98.95	9
11	297	321	92.5				-19
12	278	337	82.5				32
Final	310	352	88.1	98.83	101.10	97.75	
Total In crease	135	192	70.3	14.76	18.78	78.59	135
Av. da. Gain	1.13	1.60		0.123	0.157		

TABLE 12.

WEIGHT AND HEIGHT RECORDS.

CALF H-6

Age at Beginning, 60 days.				Duration of Trial, 120 days.			
10 day Period	Actual Weight	Normal Weight	% of N. Weight	Actual Height	Normal Height	% of N. Height	Gain in Weight.
	lbs.	lbs.	Per ct.	cm.	cm.	Per ct.	lbs.
1	145	157	92.3	81.20	82.00	99.02	8
2	153	171	89.0				12
3	165	185	89.2				14
4	179	200	89.5	84.92	86.80	97.83	22
5	201	216	93.1				9
6	210	232	90.5				12
7	222	249	89.2	89.25	92.00	97.01	15
8	237	267	88.8				13
9	250	285	87.7				13
10	263	302	87.1	93.17	96.50	96.55	-33
11	230	318	72.3				37
12	267	334	79.9				14
Final	281	349	80.5	96.58	100.90	95.72	
Total In- crease	136	192	71.4	15.38	18.90	81.38	136
Av. da. Gain	1.13	1.60		0.128	0.158		

TABLE 13.

WEIGHT AND HEIGHT RECORDS.

CALF J-4.

Age at Beginning, 60 days.				Duration of Trial, 120 days.			
10 day Period	Actual Weight	Normal Weight	% of N. Weight	Actual Height	Normal Height	% of N. Height	Gain in Weight
	lbs.	lbs.	Per ct.	cm.	cm.	Per ct.	Lbs.
1	123	105	117.1	76.17	74.70	101.97	9
2	132	117	112.8				20
3	152	129	117.8				9
4	161	140	115.0	80.67	79.30	101.73	14
5	175	151	115.9				15
6	190	162	117.3				3
7	193	174	110.9	85.67	83.90	102.11	5
8	198	190	104.2				-22
9	176	206	85.4				26
10	202	222	91.0	87.50	89.30	97.98	18
11	220	235	93.6				17
12	237	248	95.6				13
Final	250	260	96.2	92.00	93.70	98.19	
Total In- crease	127	155	81.9	15.83	19.00	83.32	127
Av. da. Gain	1.06	1.29		0.132	0.158		

TABLE 14.

SUMMARY OF WEIGHT AND HEIGHT RECORDS.

No.	Actual Increase in Weight lbs.	Normal Increase in Weight lbs.	% of N. Increase in Weight Per ct.	Actual Increase in Height cm.	Normal Increase in Height cm.	% of N. Increase. in Height. Per ct.
Lot I.						
H-1	180	177	101.7	16.58	17.31	95.78
H-4	179	191	93.7	16.78	18.36	91.40
J-2	153	156	98.1	16.63	18.75	88.69
Av.	171	175	97.8	16.66	18.14	91.96
Lot II.						
H-2	153	192	79.7	16.33	18.78	86.95
H-3	190	191	99.5	18.44	18.24	101.10
J-3	173	156	110.9	18.07	18.75	96.37
Av.	172	180	96.7	17.61	18.59	94.81
Lot III.						
H-5	135	192	70.3	14.76	18.78	78.59
H-6	136	192	71.4	15.38	18.90	81.38
J-4	127	155	81.9	15.83	19.00	83.32
Av.	133	180	74.5	15.32	18.89	81.10

TABLE 15.

FEED AND NUTRIENTS CONSUMED.

CALF H-1.

Ten-day Period	Milk	Calf Mixture A	Alfalfa Hay	Digest. Crude Protein	Net Energy	Gain in Weight	Normal Gain in Weight.
	lbs.	lbs.	lbs.	lbs.	Therms	lbs.	lbs.
1	80	20.00	14.00	6.784	32.3702	6	14
2		30.00	20.00	5.750	31.0410	7	14
3		34.50	24.50	6.7715	36.2107	12	16
4		41.50	34.50	8.6785	45.8792	20	16
5		45.00	37.75	9.4465	49.2143	18	17
6		45.00	45.25	10.2415	51.7816	19	18
7		50.00	45.00	10.8200	55.7285	15	18
8		50.00	49.25	11.2705	57.1833	19	17
9		50.00	54.50	11.8270	58.9804	27	16
10		50.00	60.00	12.4100	60.8360	14	16
11		50.00	65.00	12.9400	62.5745	23	15
Total	80	466.00	449.75	106.9395	541.7997	180	177
Lbs. Food & Nutr. per lb. Gain	.44	2.589	2.498	0.5941	3.0100		

TABLE 16.

FEED AND NUTRIENTS CONSUMED.

CALF H-4.

Ten-day Period	Milk lbs.	Calf Mixture A lbs.	Alfalfa Hay lbs.	Digest. Crude Protein lbs.	Net Energy Therms	Gain in Weight lbs.	Normal Gain in Weight. lbs.
1	80	17.75	13.50	6.4588	30.9845	4	14
2	45	29.50	24.50	7.7865	38.6177	16	14
3	3	38.50	29.50	7.8935	41.5775	14	16
4		43.25	35.00	8.9433	46.8616	16	16
5		45.00	41.25	9.8175	50.4124	15	17
6		45.00	40.25	9.7115	50.0701	10	18
7		45.00	45.50	10.2680	51.8671	20	18
8		50.00	42.25	10.5285	54.7881	15	17
9		50.00	46.75	11.0055	56.3275	18	16
10		49.50	49.50	11.2365	56.8656	14	16
11		48.25	56.75	11.8538	58.3391	20	15
12		50.00	59.00	12.3040	60.5207	17	14
Total	128	511.75	483.75	117.8077	597.2319	179	191
Lbs. Food & Nutr. per lb. Gain	.715	2.859	2.703	0.6531	3.3365		

TABLE 17.

FEED AND NUTRIENTS CONSUMED.

CALF J-2

Ten-day Period	Milk	Calf Mixture A	Alfalfa Hay	Digest. Crude Protein	Net Energy	Gain in Weight	Normal Gain in Weight.
	lbs.	lbs.	lbs.	lbs.	Therms	lbs.	lbs.
1	80	19.50	11.00	6.4055	30.9401	9	12
2	54	24.50	19.00	6.9225	33.9904	18	12
3	4	34.50	20.00	6.4385	35.2427	3	11
4		40.00	25.50	7.5430	40.9886	18	11
5		40.00	30.50	8.0730	42.7001	12	11
6		40.00	35.25	8.5765	44.3261	17	14
7		20.75	16.00	4.2068	22.2117	-15	16
8		35.75	36.25	8.1683	41.2408	30	16
9		45.00	40.25	9.7115	50.0701	11	15
10		45.00	40.75	9.7645	50.2412	20	13
11		30.00	29.25	6.7305	34.2073	-1	13
12		50.00	43.25	10.6345	55.1295	31	12
Total	138	425.00	347.00	93.1751	481.2886	153	156
Lbs. Food & Nutr. per 1 lb. Gain	.902	2.778	2.268	0.6090	3.1457		

TABLE 18.

FEED AND NUTRIENTS CONSUMED.

CALF H-2.

Ten-day Period	Milk	Calf Mixture B	Alfalfa Hay	Digest. Crude Protein	Net Energy	Gain in Weight	Normal Gain in Weight.
	lbs.	lbs.	lbs.	lbs.	Therms	lbs.	lbs.
1	80	20.00	14.50	7.4970	32.1933	9	14
2	24	19.75	10.75	5.0450	22.6988	-2	14
3	12	29.25	20.50	7.1095	31.8155	6	15
4		30.25	24.00	7.2025	32.0855	3	16
5		39.50	28.25	9.0775	40.8394	18	16
6		45.00	38.75	11.0375	48.7736	23	18
7		45.00	39.25	11.0905	48.9448	9	18
8		45.00	42.25	11.4085	49.9717	19	18
9		45.00	40.75	11.2495	49.4582	15	16
10		50.00	46.25	12.6025	55.2864	15	16
11		50.00	50.00	13.0000	56.5700	20	16
12		43.25	54.50	12.4375	52.7839	18	15
Total	116	462.00	409.75	118.7575	521.4211	153	192
Lbs. Food & Nutr. per lb. Gain	.758	3.020	2.678	0.7762	3.4080		

TABLE 19.

FEED AND NUTRIENTS CONSUMED.

CALF H-3.

Ten-day Period	Milk	Calf Mixture B	Alfalfa Hay	Digest. Crude Protein	Net Energy	Gain in Weight	Normal Gain in Weight.
	lbs.	lbs.	lbs.	lbs.	Therms	lbs.	lbs.
1	80	19.00	8.50	6.7070	29.3504	9	14
2	45	29.50	20.25	8.3095	36.6495	19	16
3	3	36.50	28.25	8.7235	38.9014	11	16
4		40.00	30.75	9.4195	42.0897	16	16
5		43.00	39.75	10.8355	47.5377	23	17
6		45.00	38.75	11.0375	48.7736	10	18
7		45.00	43.25	11.5145	50.3140	16	18
8		45.00	42.00	11.3820	49.8861	22	17
9		50.00	50.00	13.0000	56.5700	14	16
10		50.00	51.00	13.1060	56.9123	18	16
11		43.75	39.00	10.8715	47.8728	6	14
12		50.00	54.75	13.5035	58.1959	26	13
Total	128	496.75	446.25	128.4100	563.0534	190	191
Lbs. Food & Nutr. per lb. Gain	.674	2.614	2.349	0.6758	2.9634		

TABLE 20.

FEED AND NUTRIENTS CONSUMED.

CALF J-3.

Ten-day Period	Milk	Calf Mixture B	Alfalfa Hay	Digest. Crude Protein	Net Energy	Gain in Weight	Normal Gain in Weight.
	lbs.	lbs.	lbs.	lbs.	Therms	lbs.	lbs.
1	84	11.25	4.00	5.1805	22.2670	-2	12
2	93	17.50	14.00	7.5270	31.9097	16	12
3	24	28.25	22.50	7.5995	33.4282	6	11
4		34.50	25.00	7.9630	35.7814	14	11
5		39.75	25.00	8.7715	39.9242	14	11
6		38.75	31.75	9.3330	41.4456	8	14
7		39.00	37.50	9.9810	43.6111	18	16
8		33.00	31.00	8.3680	36.6516	14	16
9		45.00	39.00	11.0640	48.8592	24	15
10		45.00	46.50	11.8590	51.4264	17	13
11		49.50	46.75	12.5785	55.0629	21	13
12		50.00	48.75	12.8675	56.1421	23	12
Total	201	431.50	371.75	113.0925	496.5094	173	156
Lbs. Food & Nutr. per lb. Gain	1.162	2.494	2.149	0.6537	2.8699		

TABLE 21.

FEED AND NUTRIENTS CONSUMED.

CALF H-5.

Ten-day Period	Milk	Calf Mixt. A	Alf- alfa Hay	Tim- othy Hay	Digest. Crude Prot.	Net Energy	Gain in Wt.	N.Gain in Wt.
	LBS.	lbs.	lbs.	lbs.	lbs.	Therms	lbs.	lbs.
1	80	20.00	13.00		6.6780	32.0279	11	14
2	45	29.50	24.50		7.7865	38.6176	16	14
3	3	39.50	32.00		8.2795	43.2397	13	15
4		40.00		24.75	5.4588	40.2295	18	16
5		45.00		28.00	6.1450	45.3085	19	16
6		45.00		31.50	6.2325	46.4355	8	18
7		45.00		35.00	6.3200	47.5625	8	18
8		45.00		31.75	6.2388	46.5160	10	18
9		45.00		40.00	6.4450	49.1725	10	16
10		45.00		40.75	6.4638	49.4140	9	16
11	5	24.50	11.00	12.75	4.6293	28.3456	-19	16
12		47.00	22.00	21.00	8.5440	52.1981	32	15
Total	133	470.50	102.50	265.50	79.2212	519.0674	135	192
Lbs. Food & Nutr. per lb. Gain	.985	3.485	.759	1.967	0.5868	3.8449		

TABLE 22.

FEED AND NUTRIENTS CONSUMED.

CALF H-6.

Ten-day Period	Milk	Calf Mixt. B	Alf- alfa Hay	Tim- othy Hay	Digest. Crude Prot.	Net Energy	Gain in Wt.	N.Gain in Wt.
	lbs.	lbs.	lbs.	lbs.	lbs.	Therms	lbs.	lbs.
1	99	12.75	14.50		7.0645	29.1912	8	14
2	56	19.25	26.00		7.7365	32.1036	12	14
3		30.75	30.00		7.9155	34.5338	14	15
4		43.00		24.75	7.2408	41.9008	22	16
5		44.25		26.25	7.4708	43.3702	9	16
6		41.25		29.50	7.0900	42.0494	12	17
7		43.00		31.50	7.4095	44.0800	15	18
8		40.50		39.00	7.2120	44.5165	13	18
9		42.50		44.00	7.6450	47.7047	13	17
10		8.50		15.75	1.7028	11.7788	-33	16
11		35.25		43.75	6.5223	41.9033	37	16
12		46.25		44.50	8.2350	50.8249	14	15
Total	155	407.25	70.50	299.00	83.2447	463.9572	136	192
Lbs. Food & Nutr. per lb. Gain	1.14	2.994	.518	2.199	0.6121	3.4114		

TABLE 23.

FEED AND NUTRIENTS CONSUMED.

CALF J-4

Ten-day Period	Milk	Calf Mixt. A	Alf- alfa Hay	Tim- othy Hay	Digest. Crude Prot.	Net Energy	Gain in Wt.	N.Gain in Wt.
	lbs.	lbs.	lbs.	lbs.	lbs.	Therms	lbs.	lbs.
1	74	20.25	18.50		7.0753	33.2535	9	12
2	48	30.75	23.00		7.8868	39.5416	20	12
3		35.00	27.50		7.1500	37.6397	9	11
4		40.00		25.50	5.4775	40.4710	14	11
5		45.00		21.50	5.9825	43.2155	15	11
6		45.00		20.00	5.9450	42.7325	3	12
7		45.00		14.00	5.7950	40.8005	5	16
8	20	5.00	5.00	3.00	1.9300	9.5720	-22	16
9		35.25	14.50	16.00	6.2023	38.5444	26	16
10		50.00		33.00	6.8750	50.9510	18	13
11		50.00		39.50	7.0375	53.0440	17	13
12		50.00		44.50	7.1625	54.6540	13	12
Total	142	451.25	88.50	217.00	74.5194	484.4197	127	155
Lbs. Food & Nutr. per lb. Gain	1.117	3.553	.697	1.709	0.5868	3.8143		

TABLE 24.

FOOD AND NUTRIENTS CONSUMED FOR EACH POUND OF GAIN.

No.	Milk lbs..	Grain lbs.	Hay lbs.	Dig. Cr. Protein lbs.	Net Energy Therms
Lot I.					
H-1	0.444	2.589	2.498	0.5941	3.0100
H-4	0.715	2.859	2.703	0.6531	3.3365
J-2	0.902	2.778	2.268	0.6090	3.1457
Av.	0.687	2.742	2.490	0.6187	3.1641
Lot II.					
H-2	0.758	3.020	2.678	0.7762	3.4080
H-3	0.674	2.614	2.349	0.6758	2.9634
J-3	1.162	2.494	2.149	0.6537	2.8699
Av.	0.865	2.709	2.392	0.7019	3.0804
Lot III.					
H-5	0.985	3.485	2.726	0.5868	3.8449
H-6	1.140	2.994	2.717	0.6121	3.4114
J-4	1.117	3.553	2.406	0.5868	3.8143
Av.	1.081	3.344	2.616	0.5952	3.6902

TABLE 25.

TOTAL FEED AND NUTRIENTS CONSUMED.

No.	Milk lbs.	Grain lbs.	Hay lbs.	Digest. Crude Protein lbs.	Net Energy Therms	Av. Daily Gain lbs.
Lot I.						
H-1	80	466.00	449.75	106.9395	541.7997	1.64
H-4	128	511.75	483.75	117.8077	597.2319	1.49
J-2	138	425.00	347.00	93.1751	481.2886	1.28
Total	346	1402.75	1280.50	317.9223	1620.3202	1.47
Lot II.						
H-2	116	462.00	409.75	118.7575	521.4211	1.28
H-3	128	496.75	446.25	128.4100	563.0534	1.58
J-3	201	431.50	371.75	113.0925	496.5094	1.44
Total	445	1390.25	1227.75	360.2600	1580.9839	1.43
Lot III.						
H-5	133	470.50	368.00	79.2212	519.0674	1.13
H-6	155	407.25	369.50	83.2447	463.9572	1.13
J-4	142	451.25	305.50	74.5194	484.4197	1.06
Total	430	1329.00	1043.00	236.9853	1467.4443	1.11

FIGURE 1.

Lot I.

These three calves received Calf Mixture A (the basal ration), and alfalfa hay. The graph shows that their gains compare very favorably with the normal. They all drop slightly behind the normal rate of growth in height, but two finished above normal. Between 120 and 150 days, Calf J-2 was badly constipated.

FIGURE 2.

Lot II.

FIGURE 3.

Lot III.

These three calves were fed grain mixtures similar to the other lots, but received timothy hay from the time they were 90 days old. All calves fell behind normal in both weight and height. Pronounced dips near end of weight curves indicate period of sickness.

FIGURE 4.

Lots I., II., and III.

Lot I., fed on Calf Mixture A (the basal ration), and alfalfa hay, from the age of about 60 to 180 days, made nearly normal growth.

Lot II., which received Calf Mixture B (containing blood meal), and alfalfa hay, made no better gains than Lot I.

Lot III. was fed the same grain mixtures as the other two groups, but received timothy hay from the time they were three months old. The lot dropped behind normal and does not compare well with the other two groups.

PLATE I.

CALF H-1.

LOT I.

At Close of Experiment.

Age, 179 days.

Average daily gain, 1.64 lbs.

Weight, 357 lbs. (102.9% of Normal)

Height, 99.83 cm. (101.7% of Normal)

Ration:

Calf Mixture A (Corn 40, Bran 10, Linseed Meal 10)

Alfalfa Hay.

PLATE II.

CALF H-4.

LOT I.

At Close of Experiment.

Age, 189 days.

Average daily gain, 1.49 lbs.

Weight, 359 lbs. (99.4% of Normal)

Height, 102.25 cm. (101.8% of Normal)

Ration:

Calf Mixture A (Corn 40, Bran 10, Linseed Meal 10)

Alfalfa Hay.

PLATE III.

CALF J-2.

Lot I.

At Close of Experiment.

Age, 185 days.

Average daily gain, 1.28 lbs.

Weight, 290 lbs. (108.6% of Normal)

Height, 96.17 cm. (102.09% of Normal)

Ration:

Calf Mixture A (Corn 40, Bran 10, Linseed Meal 10)

Alfalfa Hay.

PLATE IV.

CALF H-2.

LOT II.

At Close of Experiment.

Age, 182 days.

Average daily gain, 1.28 lbs.

Weight, 328 lbs. (93.2% of Normal)

Height, 100.5 cm. (99.41% of Normal)

Ration:

Calf Mixture B (Corn 40, Bran 10, Linseed Meal 5,
Blood Meal 5)

Alfalfa Hay.

PLATE V.

CALF H-3.

LOT II.

At Close of Experiment.

Age, 191 days.

Average daily gain, 1.58 lbs.

Weight, 347 lbs. (95.6% of Normal)

Height, 102.33 cm. (100.32% of Normal)

Ration:

Calf Mixture B (Corn 40, Bran 10, Linseed Meal 5,
Blood Meal 5)

Alfalfa Hay.

PLATE VI.

CALF J-3.

LOT II.

At Close of Experiment.

Age, 185 days.

Average daily gain, 1.44 lbs.

Weight, 303 lbs. (113.5% of Normal)

Height, 96.0 cm. (101.91% of Normal)

Ration:

Calf Mixture B (Corn 40, Bran 10, Linseed Meal 5,
Blood Meal 5)

Alfalfa Hay.

PLATE VII.

CALF H-5.

LOT III.

At Close of Experiment.

Age, 182 days.

Average daily gain, 1.13 lbs.

Weight, 310 lbs. (88.1% of Normal)

Height, 98.83 cm. (97.75% of Normal)

Ration:

Calf Mixture A (Corn 40, Bran 10, Linseed Meal 10)

Alfalfa Hay (From 62 to 92 days old)

Timothy Hay (From 92 to 182 days old)

PLATE VIII.

CALF H-6.

LOT III.

At Close of Experiment.

Age, 180 days.

Average daily gain, 1.13 lbs.

Weight, 281 lbs. (80.5% of Normal)

Height, 96.58 cm. (95.72% of Normal)

Ration:

Calf Mixture B (Corn 40, Bran 10, Linseed Meal 5,
Blood Meal 5)

Alfalfa Hay (From 60 to 90 days old)

Timothy Hay (From 90 to 180 days old)

PLATE IX.

CALF J-4.

LOT III.

At Close of Experiment.

Age, 180 days.

Average daily gain, 1.06 lbs.

Weight, 250 lbs. (96.2% of Normal)

Height, 92.0 cm. (98.19% of Normal)

Ration:

Calf Mixture A (Corn 40, Bran 10, Linseed Meal 10)

Alfalfa Hay (From 60 to 90 days old)

Timothy Hay (From 90 to 180 days old)

BIBLIOGRAPHY.

1. Abderhalden, E. Nitrogenous Metabolism.
1916 Jour. of the Chem. Society,
Vol. 110, Part 1, pp. 580-581.
2. Ackroyd, H. and Hopkins, F.G.
1916 Feeding Experiments with Deficiencies in the Amino Acid Supply.
Biochemical Jour. Vol. 10,
pp. 551-576.
3. Alsberg, C.L.
1916 The Biochemical Analysis of Nutrition.
Jour. of the Washington Acad. of Sciences, Vol. 6, pp. 269-280.
4. Anon, - - -
1917 Interrelationship of the Thyroid and the Adrenals.
Endocrinology, Vol. 1, pp. 404-408.
5. Archibald, E.S.
1915 Calf Feeding Experiments.
Can. Exp. Farms Report (1915) p. 405.
6. Armsby, H. P.
1917 The Nutrition of Farm Animals.
New York, The MacMillan Co., 1917.
7. Aron, H.
1911 Nutrition and Growth.
The Philippina Jour. Science, Vol. B-6, pp. 1-50.
8. Aron, H.
1912 Influence of Quality and Quantity of the Food upon the Growing Organism.
Trans. 15th Internat. Cong. on Hygiene and Demography, Vol. 2, pp. 451-456.
9. Ascoli, G. and Legnani, F.
1912 Changes Following the Extirpation of the Pituitary Body.
Chem. Abst. Vol. 6, No. 23, p. 3452.
10. Baldassare, S.
1897 Meat Meal for Calf Feeding.
Abstract, Exp. Sta. Record, Vol. 9, p. 1079.

11. Bayliss, W. M.
1915 Principles of General Physiology.
London; Longmans, Green & Co., 1915.
12. Beach, C.L.
1906 The Facility of Digestion of Foods
as a Factor in Feeding.
Storrs Agr. Exp. Sta. Bulletin 43.
13. Besana, C.
1903 Experiments on the Utilization of
Skim Milk for Calf Feeding.
Abstract Exp. Sta. Record, Vol. 15,
p. 393.
14. Besana, C.
1911 On Substituting a Foreign Fat for
Milk Fat in Feeding Skim Milk to
Calves.
Abstract Exp. Sta. Record, Vol. 25,
p. 674.
15. Brainerd, W.K. and Davis, H.P.
1917 Feeding and Management of Dairy Calves
and Young Dairy Stock.
Farmers Bulletin 777, U.S. Dept. of Agr.
16. Buckner, G.D., Nollau, E.H., and Kastle, J.H.
1915 The Feeding of Young Chicks on Grain
Mixtures of High and Low Lysine
Content. ?
17. Bywaters, H.W.
1914 Vitamines.
Science Progress in the 20th Cent.
Vol. 9, pp. 225-250.
18. Chapin, H.D.
1913 The Double Function of Fats and
Carbohydrates in Nutrition, and
Their Nutritive Properties.
New York Med. Jour. Vol. 97, No. 6,
pp. 269-273.
19. Chick, H. and Hume, M.
1917 The Distribution in Wheat, Rice and
Maize Grains of the Substance,
Deficiency of which in the Diet
Causes Polyneuritis in Birds and
Beri-beri in Man.
Proceedings of the Royal Society,
Ser. B., Vol. 90, No. B-624,
pp. 44-60.
20. Chick, H. and Hume, E.M., and Skelton, R.F.
1918 Biochem. Jour. Vol. 12, pp. 131-153.
The Anti-scorbutic Value of Cow's
Milk.

21. Chiesi, A.
1911
Margarin in Milk for Fattening Calves.
Abstract, Exp. Sta. Record, Vol. 25,
p. 774.
22. Cottrell, H.M., and Otis, D.H.
1900
Calf Feeding Experiments.
Kansas Agr. Exp. Sta. Bulletin 97.
23. Cramer, W.
1916
On the Biochemical Mechanism of Growth.
Jour. of Physiol. Vol. 50, pp. 322-334.
24. Crawford, A.
1900
Milk Substitutes for Calves.
Abstract Exp. Sta. Record, Vol. 12,
p. 282.
25. Curtiss, C.F.
1892
Experiments in Calf Feeding.
Iowa Agr. Exp. Sta. Bulletin 19.
26. Curtiss, C.F.
1894 .
Calf Feeding.
Iowa Agr. Exp. Sta. Bulletin 25.
27. Curtiss, C.F.
1897
Feeding Separator Milk to Calves.
Iowa Agr. Exp. Sta. Bulletin 35.
28. Dean, H.H.
1903
Calf Feeding.
Abstract Exp. Sta. Record, Vol. 15,
p. 1103.
29. Dean, H.H.
1900
Calf Feeds.
26th An. Report, Ont. Agr. College
and Exp. Farm, 1900, p. 43.
30. Dean, H.H.
1905
Bran, Oats, and Oil Cake compared
with Bran and Blatchford's Calf Meal
for Feeding Calves.
Report, Ont. Agr. College and Exp.
Farm, 1905, p. 126.
31. Dechambre,
1914
Feeding Calves on Skim Milk and
Cassava Meal.
Abstract, Exp. Sta. Record, Vol. 30,
p. 768.
32. Dickson, D. and Malpeaux, L.
1900
Milk and Artificial Foods for
Fattening Calves.
Abstract Exp. Sta. Record, Vol. 12,
p. 978.

33. Dolsciue, A. 1907 Diastasolin in Feeding Calves.
Abstract Exp. Sta. Record, Vol. 19,
p. 1068.
34. Dornic, P. and Daire, P. 1908 Raising and Fattening Calves on
Skim Milk with and without Supple-
mentary Feeds.
Abstract Exp. Sta. Record, Vol. 20,
p. 176.
35. Drummond, J.C. 1917 A Study of the Water-soluble
Accessory Growth Promoting Substance
in Yeast, I.
Biochem. Jour. Vol. 11, pp. 255-272.
36. Drummond, J.C. 1918 A Study of the Water-soluble Acces-
sory Growth Promoting Substance, II.
Its Influence upon the Nutrition and
Nitrogen Metabolism of the Rat.
Biochem. Jour. Vol. 12, pp. 25-41.
37. Dunstan, M.J.R. 1905 Calf Rearing.
Abstract Exp. Sta. Record, Vol. 17,
p. 795.
38. Dutcher, R.A. and Collatz, F.A. 1918 Does Water-Soluble Vitamine Function
as a Catalase Activator?
Jour. Biol. Chem. Vol. 36, pp. 547-
550.
39. Eckles, C.H. 1915 The Ration and Age of Calving as
Factors Influencing the Growth and
Dairy Qualities of Cows.
Missouri Exp. Sta. Bulletin 135.
40. Eckles, C.H. 1913 Raising Calves on Skim Milk.
Missouri Agr. Exp. Sta. Circular 47.
41. Edin, H. 1917 Feeding Calves with Skim Milk and
Partially Hydrolyzed Starch.
Abstract Exp. Sta. Record, Vol. 36,
p. 370.
42. Fain, J.R. and Jarnagin, M.P. 1907 Skim Milk for Calf Feeding.
Virginia Agr. Exp. Sta. Bulletin 172.

43. Fenger, F.
1912 On the Presence of Active Principles
in the Thyroid and Suprarenal Glands
Before and After Birth.
Jour. Biol. Chem. Vol. 11, pp. 489-
492.
44. Fenger, F.
1912 On the Presence of Active Principles
in the Thyroid and Suprarenal Glands
Before and After Birth.
Jour. Biol. Chem. Vol. 12, pp. 55-59.
45. Florida Annual Report.
1915. Calf Feeding Trials.
Florida Annual Report, 1915, pp.
xxi-xxii.
46. Forbes, E.B.
1909 The Mineral Elements in Animal
Nutrition.
Ohio Agr. Exp. Sta. Bulletin 201.
47. Forbes, E.B.
1916 The Mineral Nutrients in Practical
Human Dietetics.
Scientific Monthly, Vol. 2, pp. 282-
289.
48. Forbes, E.B.
1916 Studies on the Mineral Elements in
Animal Nutrition.
Jour. Wash. Acad. Sciences, Vol. 6,
pp. 431-446.
49. Foulkes, P. H., Andrews, A., and Garnett, J.B.
1915 Calf Feeding Experiments.
Abstract Exp. Sta. Record, Vol. 33,
p. 570.
50. Fraser, W.J. and Brand, R.E.
1913 Milk Required to Raise a Dairy Calf.
Illinois Agr. Exp. Sta. Bulletin 164.
51. French, H.T.
1905 Raising Calves on Skim Milk.
Idaho Agr. Exp. Sta. Bulletin 48.
52. Funk, C.
1916 The Nature of the Disease Due to
the Exclusive Diet of Oats in Guinea
Pigs and Rabbits.
Jour. Biol. Chem. Vol. 25, pp. 409-
416.
53. Funk, C. and Douglas, M.
1913 The Relationship of Beri-beri to
Glands of Internal Secretion.
Jour. of Physiol., Vol. 47, pp. 475-
478.

54. Garrison, F.H.
1915 Ductless Glands, Internal Secretions
and Hormonic Equilibrium.
Popular Science Mo. Vol. 86, pp. 142-
152.

55. Gazette, Agricultural.
1916 Agricultural Gazette, London.
Calf Feeding Trials.
Vol. 83, No. 2201, pp. 151-152.

56. Geiling, E.M.K.
1917 The Nutritive Value of the Diamino
Acids Occurring in Proteins for the
Maintenance of Adult Mice.
Jour. Biol. Chem., Vol. 31, pp. 173-
199.

57. Giuliani, R.
1914 Calf Feeding with Blatchford's Calf
Meal.
Int. Inst. of Agr. Bureau of Agr.
Intel. and Plant Diseases, Year V.
No. 4, pp. 509-510.

58. Gley, E.
1913 Internal Secretions.
British Med. Jour., Part 2 (1913)
pp. 374-375.

59. Goetsch, E.
1916 The Influence of Pituitary Feeding
upon Growth and Sexual Development.
Bulletin of the Johns Hopkins Hosp.,
Vol. 27, No. 300, pp. 29-50.

60. Gouin, A. and Andouard, P.
1907 Feeding Calves with Starch and Skim
Milk.
Abstract Exp. Sta. Record, Vol. 19,
p. 468.

61. Gouin, A. and Andouard, P.
1909 Tapioca Flour for Raising Calves.
Abstract, Exp. Sta. Record, Vol.
21, p. 569.

62. Gouin, A. and Andouard, P.
1914 Feeding of Calves on Skim Milk and
Cassava Porridge.
Bul. Soc. Nat. Agr. France, Vol.
74, No. 1, pp. 40-42.

63. Gridley, H.S., Joseph, W.E., and Slater, M.E.
1915 Quantitative Determination of the
Amino Acids of Feeding-Stuffs by
the Van Slyke Method.
Jour. Am. Chem. Soc. Vol. 37,
pp. 1778-1750.

64. ⁿ
Gridley, H.S., Joseph, W.E., and Slater, M.E.
1915 Quantitative Determination of the
 Amino Acids of Feeding-Stuffs by
 the Van Slyke Method.
 Jour. Am. Chem. Soc. Vol. 37,
 pp. 2762-2768.
65. Gudernatsch, J.F.
1914 A Further Contribution to the
 Knowledge of Organs with Internal
 Secretions.
 Am. Jour. of Anat. Vol. 15, pp.
 431-482.
66. Guthrie, F.B.
1902 Substitutes for Cream in Skim
 Milk as Calf Food.
 Agr. Gaz. New South Wales, Vol. 13,
 No. 12, p. 1247.
67. Haecker, T.L.
1894 Skim Milk for Calf Raising.
 Minnesota Agr. Exp. Sta. Bulletin 35.
68. Haecker, A.L.
1901 Comparison of Skim Milk Calves with
 Those which Sucked their Dams.
 Nebraska Agr. Exp. Sta. Bulletin 68.
69. Haecker, A.L.
1905 A Test of Calf Rations.
 Nebraska Agr. Exp. Sta. Bulletin 87.
70. Halliburton, W.D. and Drummond, J.C.
1917 The Nutritive Value of Margarine
 and Butter Substitutes with Refer-
 ence to Their Content of the Fat-
 Soluble Accessory.
 Jour. Physiol. Vol. 51, pp. 235-51.
71. Hangel, G.
1907 Milk Emulsion for Calf Feeding.
 Abstract, Exp. Sta. Record,
 Vol. 19, p. 468.
72. Hanne, R.
1907 Feeding Inverted Starch to Calves.
 Abstract, Exp. Sta. Record, Vol. 19,
 p. 1068.
73. Hansen, J.
1907 Feeding Saccharified Starch.
 Abstract, Exp. Sta. Record, Vol. 19,
 p. 968.
74. Hart, E.B. and McCollum, E.V.
1916 Growth on Strictly Vegetable Diets.
 Jour. Biol. Chem. Vol. 24, pp. xxviii-
 xxix.

75. Hart, E.B., McCollum, E.V., and Fuller, J.G.
1909 The Role of Inorganic Phosphorus
in the Nutrition of Animals.
Wisconsin Agr. Exp. Sta. Research
Bulletin 1.
76. Hart, E.B., McCollum, E.V., Steenbock, H., and
1911 Humphrey, G.C.
Physiological Effect on Growth and
Reproduction of Rations Balanced
from Restricted Sources.
Wisconsin Agr. Exp. Sta. Research
Bulletin 17.
77. Hart, E.B., Miller, W.S., and McCollum, E.V.
1916 Further Studies on the Nutritive
Deficiencies of Wheat and Grain
Mixtures and the Pathological
Conditions Produced in Swine by
Their Use.
Jour. Biol. Chem. Vol. 25, pp. 239-
259.
78. Haselhoff, E.
1908 Experiments with Diastasolin in
the Feeding of Calves.
Abstract, Exp. Sta. Record, Vol. 20,
p. 568.
79. Hayden, C.C.
1915 Raising Dairy Heifers.
Ohio Agr. Exp. Sta. Bulletin 289.
80. Hayward, H.
1902 The Rearing of Calves on Milk
Substitutes.
Pennsylvania Agr. Exp. Sta. Bulletin
60.
81. Hendrick, J.
1913 Calf Feeding Experiments with
Separated Milk and Oils.
Trans. of the Highland and Agr.
Soc. of Scotland, 5th Series,
Vol. 25, pp. 259-282.
82. Henry, W.A. and Morrison, F.B.
1916 Feeds and Feeding. 16th edition.
Madison, Wis. The Henry & Morrison
Co. 1916.
83. Hittcher, G.
1910 Calf Feeding Experiments.
Abstract Exp. Sta. Record, Vol. 22,
p. 774.

84. Hogan, A.G.
1916 The Nutritive Properties of Corn.
Jour. Biol. Chem. Vol. 27, pp.
193-208.
85. Hogan, A.G.
1917 Corn as a Source of Protein and
Ash for Growing Animals.
Jour. Biol. Chem. Vol. 29, pp.
485-493.
86. Hopper, J.J.
1913 Experiments in Feeding Dairy Cows
and Calves.
Kentucky Agr. Exp. Sta. Bulletin
171.
87. Hopkins, F.G.
1912 Feeding Experiments Illustrating
the Importance of Accessory Factors
in Normal Dietaries.
Jour. of Physiol. Vol. 44, pp. 425-
460.
88. Hopkins, F.G.
1916 Newer Standpoints in the Study of
Nutrition.
Jour. Chem. Soc. Vol. 109, pp.
629-249.
89. Howell, W.H.
1915 Physiology. Sixth Edition.
Philadelphia.
W. B. Saunders & Co. 1915.
90. Hubbard, W.W.
1915 Calf Feeding Experiments.
Canada Exp. Farms Report 1915,
p. 440.
91. Hulce, R.S. and Nevens, W.B.
1917 Feed and Care of the Dairy Calf.
Illinois Agr. Exp. Sta. Circular
202.
92. Hunt, T.F. and Zink, C.H., Jr.
1891 The Economical Rearing of Calves.
Pennsylvania Agr. Exp. Sta. Annual
Report for 1891, pp. 112-117.
93. Hunziker, O.F. and Caldwell, R.E.
1916 Skim Milk and Milk Substitutes for
Calf Feeding.
Purdue Univ. Agr. Exp. Sta.
Bulletin 193.

94. Hunziker, O.F.
1917
Purdue Univ. (Indiana) Agr. Exp.
Sta. Annual Report, 1917.
Calf Feeding.
95. Hutton, G.H.
1915
Calf Feeding Experiments.
Canada Exp. Farms Reports 1915,
p. 445.
96. Iscovesco, H.
1914
Physiology of the Anterior Lobe of
the Hypophysis; the Lipoid of this
Lobe.
Abstract, Chem. Abst. Vol. 8, No. 8,
p. 1464.
97. Iscovesco, H.
1914
Action on the Organism of a Lipoid
Extracted from the Ovary.
Abstract, Chem. Abst. Vol. 8, No. 6,
p. 1163.
97. Iscovesco, H.
1914
Physiological Action of a Lipoid
Extracted from the Testicle.
Abstract, Chem. Abst. Vol. 8, No. 6,
p. 1163.
98. Iscovesco, H.
1914
Physiological Action, especially on
Growth, of a Lipoid Extracted from
the Thyroid.
Abstract, Chem. Abst. Vol. 8, No. 8,
p. 1453.
99. Jordan, W.H.
1909
The Feeding of Animals.
New York.
The MacMillan Co., 1909.
100. Journal of the Board of Agriculture.
1917
London. Calf Rearing.
Vol. 24, No. 9, pp. 974-976.
101. Journal, Dept. Agr. and Tech. Inst.
1903
Ireland.
Vol. 3, No. 4, pp. 627-647.
Calf Rearing Experiments.
102. Journal, Dept. Agr. and Tech. Inst.
1916
Ireland.
Calf Feeding Experiments.
Vol. 16, pp. 421-424.
Vol. 17, pp. 257-259.
103. Kahn, R.H.
1916
Action of Thyroid and Thymus on
Tadpoles.
Abstract, Chem. Abst. Vol. 11,
No. 6, p. 673.

104. Käppeli, J.
1903 Kälberrahm with Skim Milk as a Milk Substitute in Calf Feeding. Abstract, Exp. Sta. Record, Vol. 15, p. 893.
105. Kellicott, W.E.
1910 A Contribution to the Theory of Growth. Abstract, Exp. Sta. Record Vol. 29, p. 64.
107. Kellner, O.
1913 The Scientific Feeding of Animals. New York. The MacMillan Co., 1913.
108. Kerekes, G.
1914 Calf Rearing Experiments in Hungary. Abstract in Internat. Inst. of Agr. Mo. Bulletin Bureau of Agr. Intel. and Plant Diseases 5, No. 11, pp. 1473-1475.
109. Lindsey, J.B.
1893 Feeding Experiments with Calves. Massachusetts Agr. Exp. Sta. Ann. Report 1893, pp. 125-145.
110. Lindsey, J.B.
1894 Feeding Experiments with Calves. Massachusetts Agr. Exp. Sta. 16th Annual Report 1894, pp. 125-146.
111. Lindsey, J.B.
1903 Calf Feeding Experiments. Massachusetts Hatch Exp. Sta. 16th An. Report, pp. 80-86.
112. Lindsey, J.B.
1915 Substitutes for Milk in the Rearing of Dairy Calves. Massachusetts Agr. Exp. Sta. Bulletin 164.
113. Linfield, F.B.
1898 Experiments in Calf Feeding. Utah Agr. Exp. Sta. Bulletin 57.
114. Loeb, J.
1915 The Stimulation of Growth. Science, N.S. Vol. 41, pp. 704-715.
116. McCollum, E.V.
1914 The Value of the Proteins of the Cereal Grains and of Milk for Growth in the Pig, and the Influence of the Plane of Protein Intake on Growth. Jour. Biol. Chem. Vol. 19, pp. 323-333.

117. McCollum, E.V.
1917 Relation of the Dairy Industry to
the Public Health.
Hoard's Dairyman, Vol. 54, Dec.
21, 1917.
118. McCollum, E.V.
1918 The Newer Knowledge of Nutrition.
New York.
The MacMillan Co., 1918.
119. McCollum, E.V. and Davis, M.
1915 Essential Factors in the Diet
During Growth.
Jour. Biol. Chem. Vol. 23, pp.
231-246.
120. McCollum, E.V. and Kennedy, C.
1916 The Dietary Factors Operating in
the Production of Polyneuritis.
Jour. Biol. Chem. Vol. 24, pp. 491-
502.
121. McCollum, E.V. and Pitz, W.
1917 The "Vitamine" Hypothesis and
Deficiency Diseases.
Jour. Biol. Chem., Vol. 31, pp.
229-253.
122. McCollum, E.V. and Simmonds, N.
1917 The Minimum Requirements of the Two
Unidentified Dietary Factors for
Maintenance as Contrasted with Growth.
Jour. Biol. Chem. Vol. 32, pp.
181-193.
123. McCollum, E.V. and Simmonds, N.
1917 The Values of Some Seed Proteins
for Maintenance.
Jour. Biol. Chem., Vol. 32, pp.
347-368.
124. McCollum, E.V. and Simmonds, N.
1918 The Causes of Failure of Mixtures
of Seeds to Promote Growth in
Young Animals.
Jour. Biol. Chem. Vol. 33, pp.
303-311.
125. McCollum, E.V., Simmonds, N., and Pitz, W.
1916 The Distribution in Plants of the
Fat-Soluble A, the Dietary Essen-
tial of Butter Fat.
Am. Jour. Physiol, Vol. 41, pp.
361-375.

126. McCollum, E.V., Simmonds, N., and Pitz, W.
1916 The Nature of the Dietary Deficiencies of the Wheat Embryo.
Jour. Biol. Chem. Vol. 25, pp. 105-131.
127. McCollum, E.V., Simmonds, N., and Pitz, W.
1916 The Relation of the Unidentified Dietary Factors, the Fat-soluble A, and Water-soluble B, of the Diet to the Growth-promoting Properties of Milk.
Jour. Biol. Chem. Vol. 27, pp. 33-43.
128. McCollum, E.V., Simmonds, N., and Pitz, W.
1916 Dietary Deficiencies of the Maize Kernel.
Jour. Biol. Chem. Vol. 28, pp. 153-165.
129. McCollum, E.V., Simmonds, N., and Pitz, W.
1916 The Effects of Feeding the Proteins of the Wheat Kernel at Different Planes of Intake.
Jour. Biol. Chem. Vol. 28, pp. 211-229.
130. McCollum, E.V., Simmonds, N., and Pitz, W.
1917 Is Lysine the Limiting Amino-Acid in the Proteins of Wheat, Maize, or Oats?
Jour. Biol. Chem., Vol. 28, pp. 483-499.
131. McCollum, E.V., Simmonds, N., and Pitz, W.
1917 The Nature of the Dietary Deficiencies of the Oat Kernel.
Jour. Biol. Chem., Vol. 29, - pp. 341-354.
132. McCollum, E.V., Simmonds, N., and Pitz, W.
1917 The Supplementary Dietary Relationship Between Leaf and Seed as Contrasted with Combinations of Seed with Seed.
Jour. Biol. Chem. Vol. 30, pp. 13-32.

133. McCord, C.P.
1915
The Occurrence of Pituitrin and Epinephrin in Fetal Pituitary and Suprarenal Glands.
Jour. Biol. Chem., Vol. 23, pp. 435-438.
134. Mahon, J.
1905
Calf Feeding Experiments.
Abstract, Exp. Sta. Record, Vol. 17, p. 277.
135. Malpeaux, L.
1908
Skim Milk for Raising and Fattening Calves.
Abstract, Exp. Sta. Record, Vol. 20, p. 175.
136. Maswersit, J.
1898
Successful Use of Starch and Skim Milk for Calves.
Abstract, Exp. Sta. Record, Vol. 10, p. 780.
137. Mathews, A.P.
1916
Physiological Chemistry.
Second Edition.
New York.
Wm. Wood & Co., 1916.
138. Mendel, L.B.
1913
Viewpoints in the Study of Growth.
Biochem. Bulletin No. 3, pp. 156-176.
139. Mendel, L.B.
1915
Nutrition and Growth.
Jour. Am. Med. Assoc., Vol. 64, pp. 1539-1547.
140. Michels, J.
1908
Rolled Oats as a Partial Substitute for Milk in Calf Feeding.
North Carolina Agr. Exp. Sta. Bulletin 199.
141. Minot, C.S.
1908
The Problem of Age, Growth and Death.
New York.
G. P. Putnam's Sons. 1908.
142. Misson, L.
1907
Artificial Feeding of Calves.
Abstract, Exp. Sta. Record, Vol. 19, p. 1068.
143. Mitchell, H.H.
1916
Feeding Experiments on the Substitution of Protein by Definite Mixtures of Isolated Amino-Acids.
Jour. Biol. Chem. Vol. 26, pp. 231-261.

144. Moore, J.S.
1903 Calf Feeding Experiments.
Mississippi Agr. Exp. Sta. 16th
Annual Report, pp. 18 and 19.
145. Morse, F.W.
1898 Cost of Raising Calves.
New Hampshire Agr. Exp. Sta.
Bulletin 58.
146. Moser, C. and Käppeli, J.
1902 Cremaval as a Supplement to Skim
Milk in Calf Feeding.
Abstract, Exp. Sta. Record, Vol. 14,
p. 1108.
147. Müller, W. and VonWendt, G.
1911 Diastasolin for Calf Feeding.
Abstract, Exp. Sta. Record, Vol. 25,
p. 581.
148. Mumford, F.B.
1917 The Breeding of Animals.
New York.
The MacMillan Co., 1917.
149. Nollau, E.H.
1915 The Amino-Acid Content of Certain
Commercial Feeding Stuffs and Other
Sources of Protein.
Jour. Biol. Chem. Vol. 21, --
pp. 611-614.
150. Norton, H.W., Jr.
1909. Rearing Calves on Skim Milk and
Supplementary Feed.
Michigan Agr. Exp. Sta. Bulletin 257.
151. Osborne, T.B. and Mendel, L.B.
1914 Amino Acids in Nutrition and Growth.
Jour. Biol. Chem. Vol. 17, pp.
325-349.
152. Osborne, T.B. and Mendel, L.B.
1914 The Suppression of Growth and the
Capacity to Grow.
Jour. Biol. Chem., Vol. 18, pp. 95-
106.
153. Osborne, T.B. and Mendel, L.B.
1915 Comparative Nutritive Value of
Certain Proteins in Growth, and the
Problem of the Protein Minimum.
Jour. Biol. Chem., Vol. 20, pp.
351-390.

154. Osborne, T.B. and Mendel, L.B.
1915 Further Observations of the Influence of Natural Fats upon Growth.
Jour. Biol. Chem., Vol. 20, pp. 379-389.
155. Osborne, T.B. and Mendel, L.B.
1916 The Resumption of Growth after Long Continued Failure to Grow.
Jour. Biol. Chem., Vol. 23, pp. 439-458.
156. Osborne, T.B. and Mendel, L.B.
1916 Acceleration of Growth after Retardation.
Am. Jour. Physiol., Vol. 40, pp. 16-20.
157. Osborne, T.B. and Mendel, L.B.
1916 The Amino-Acid Minimum for Maintenance and Growth, as Exemplified by Further Experiments with Lysine and Tryptophane.
Jour. Biol. Chem., Vol. 25, pp. 1-12.
158. Osborne, T.B. and Mendel, L.B.
1916 The Effect of the Amino-Acid Content of the Diet on the Growth of Chickens.
Jour. Biol. Chem., Vol. 26, pp. 293-300.
159. Osborne, T.B. and Mendel, L.B.
1916 A Quantitative Comparison of Casein, Lactalbumin, and Edestin for Growth or Maintenance.
Jour. Biol. Chem., Vol. 26, pp. 1-25.
160. Osborne, T.B. and Mendel, L.B.
1917 The Relative Value of Certain Protein Concentrates as Supplements to Corn Gluten.
Jour. Biol. Chem., Vol. 29, pp. 69-92.
161. Osborne, T.B. and Mendel, L.B.
1917 The Use of Cotton Seed as Food.
Jour. Biol. Chem., Vol. 29, pp. 289-317.

162. Osborne, T.B. and Mendel, L.B.
1917 The Role of Vitamines in the Diet.
Jour. Biol. Chem., Vol. 31, pp.
149-163.
163. Osborne, T.B. and Mendel, L.B.
1917 Nutritive Factors in Animal Tissues.
Jour. Biol. Chem., Vol. 32, pp.
309-323.
164. Osborne, T.B. and Mendel, L.B.
1918 The Inorganic Elements in Nutrition.
Jour. Biol. Chem., Vol. 34, pp.
131-139.
165. Osborne, T.B. and Mendel, L.B.
1918 The Protein Factor in the Seeds of
Cereals.
Jour. Biol. Chem., Vol. 34, pp.
521-535.
166. Osborne, T.B. and Mendel, L.B.
1918 Milk as a Source of Water-Soluble
Vitamine.
Jour. Biol. Chem., Vol. 34, pp.
537-551.
167. Osborne, T.B. and Mendel, L.B.
1918 The Choice Between Adequate and
Inadequate Diets, as Made by Rats.
Jour. Biol. Chem., Vol. 35, pp.
19-28.
168. Otis, D.H.
1904 Experiments with Hand-fed Calves.
Kansas Agr. Exp. Sta. Bulletin 126.
169. Otis, D.H.
1910 The Dairy Calf at Meal Time.
Wisconsin Agr. Exp. Sta. Bulletin
192.
170. Petersen, M.
1895 Peanut Oil and Sour Milk for Calf
Feeding.
Abstract, Exp. Sta. Record, Vol. 7,
p. 64.
171. Pirocchi, A.
1905 Utilization of Skim Milk for Calf
Feeding.
Abstract, Exp. Sta. Record, Vol. 17,
p. 894.

172. Pirocchi, A.
1906 Skim Milk for Calf Feeding.
Abstract, Exp. Sta. Record, Vol. 18,
p. 973.
173. Pirocchi, A.
1907 Skim Milk in Calf Feeding.
Abstract, Exp. Sta. Record, Vol. 19,
p. 675.
174. Pirocchi, A.
1913 Utilization of Skim Milk as Food
for Calves.
Internat. Inst. Agr. (Rome) Mo. Bull.
Agr. Intel. and Plant Diseases 4,
No. 8, pp. 1157-1164.
175. Plumb, C.S.
1893 Skim Milk as a Food for Calves.
Purdue Univ. Agr. Exp. Sta.
Bulletin 47.
176. Proulx, E.G., Cutler, C., Deemer, R.B., Roop, J.H.,
1917 Nimitz, H.J., and Roberts, O.S.
1918 Commercial Feeding Stuffs.
Purdue Univ. Agr. Exp. Sta.
Bulletins 209 and 217.
177. Ramsden, W.
1918 Vitamines.
Jour. Soc. Chem. Ind., Vol. 37,
pp. 53-55.
178. Rarkin,
1903 Eggs as a Feeding Stuff for Calves.
Abstract, Exp. Sta. Record, Vol. 16,
p. 397.
179. Rasquin, M.
1905 Theoretical and Practical Calf
Feeding.
Abstract, Exp. Sta. Record, Vol. 17,
pp. 1003-1004.
180. Reed, O.E.
1915 Raising Calves on Skim Milk.
Kansas Agr. Exp. Sta. Circular 48.
181. Regan, W.M.
1914 Lactation on Growth.
Thesis for Degree A.M., University
of Missouri.
182. Richardson, A.E. and Green, H.S.
1916 Nutrition Investigations upon Cotton-
seed Meal.
Jour. Biol. Chem., Vol. 25, pp.
307-318.

183. Rigaux, F.
1899
Artificial Milk, or Liebig Milk,
for Calves.
Abstract, Exp. Sta. Record, Vol.
11, p. 883.
184. Robertson, T.B.
1916
The Normal Growth of the White
Mouse.
Jour. Biol. Chem., Vol. 24, pp.
363-383.
185. Robertson, T.B.
1916
The Influence of Tethelin, the
Growth-Controlling Principle of the
Anterior Lobe of the Pituitary Body,
upon the Growth of the White Mouse.
Jour. Biol. Chem., Vol. 24, pp.
397-408.
186. Robertson, T.B.
1917
Recent Investigations on the In-
fluence of the Anterior Lobe of the
Pituitary Body upon Growth and on
the Properties of the Growth-Con-
trolling Constituent, Tethelin.
Endocrinology, Vol. 1, pp. 24-39.
187. Robertson, T.B. and Delprat, M.
1917
The Influence of Tethelin upon
the Early Growth of the White
Mouse.
Jour. Biol. Chem., Vol. 31, pp.
567-574.
188. Schäfer, E.A.
1916
The Endocrine Organs.
London.
Longman's Green, & Co. (1916)
189. Schuppli, P.
1913
Calf Rearing on the Emulsion System.
Internat. Inst. Agr. (Rome) Mo.
Bull. Agr. Intel. and Plant Diseases,
Year 4, No. 2, pp. 167-173.
190. Seton, R.S.
1902
Cod Liver Oil as a Substitute for
Cream in Calf Rearing.
Abstract, Exp. Sta. Record, Vol. 14,
p. 668.
191. Somerville, W.
1900
Calf Rearing.
Abstract, Exp. Sta. Record, Vol. 11,
p. 1077.

192. Somerville, W.
1896
Calf Rearing.
County Councils Cumberland, Durham,
and Northumberland, Tech. Education,
Report 8, p. 95.
193. Steenbock, H., Boutwell, P.W., and Kent, H.E.
1918
Fat-Soluble Vitamins. I.
Jour. Biol. Chem., Vol. 35, pp.
517-526.
194. Steenbock, H., Kent, H.E., and Gross, E.G.
1918
The Dietary Qualities of Barley.
Jour. Biol. Chem., Vol. 35, pp.
61-74.
195. Thiele, H.
1909
Experiments in Raising Calves.
Abstract, Exp. Sta. Record, Vol. 21,
p. 172.
196. Thompson, H.B., and Mendel, L.B.
1918
An Experimental Study of Alternating
Growth and Suppression of Growth in
the Albino Mouse, with Special
Reference to the Economy of Food
Consumption.
Am. Jour. Physiol., Vol. 45, pp.
431-460.
197. Tracy, E.A.
1918
A Bit of Hormonology with Practical
Applications.
Medicine and Surgery, Vol. 2, pp.
35-40.
198. Trowbridge, P.F., Moulton, C.R., and Haigh, L.D.
1918
Effect of Limited Food on Growth
of Beef Animals.
Missouri Agr. Exp. Sta. Research
Bulletin 28.
199. Underhill, F.P.
1915
The Physiology of the Amino Acids.
New Haven, Conn.
Yale Univ. Press. (1915)
200. Voelcker, J.A.
1914
Calf Rearing.
Jour. of the Royal Agr. Soc. of
England, Vol. 75, pp. 51-62.
201. Washburn, R.M.
1917
Productive Dairying.
Philadelphia, Pa.
J. B. Lippincott Co. (1917)

202. Washington Agricultural Experiment Station.
1915 Wash. Agr. Exp. Sta. Annual Report,
1915, pp. 9-10.
Substitutes for Skim Milk in Feed-
ing Calves.
203. Waters, H.J.
1908 The Capacity of Animals to Grow
Under Adverse Conditions.
Proceedings of the Society for the
Promotion of Agr. Science, No. 29,
pp. 71-96.
204. Wellman, O.
1914 Skim Milk and Diafarin for Calf
Feeding.
Landw. Jahrb. 46, No. 4, pp. 526-
531.
205. Willcock, E.G. and Hopkins, F.G.
1916 The Importance of Individual Amino
Acids in Metabolism. Observations
on the Effect of Adding Tryptophane
to a Dietary in which Zein is the
Sole Nitrogenous Content.
Jour. of Physiol., Vol. 35, pp. 88-
102.
206. Wilsdorf, G.
1907 Concerning the Use of Homogenized
Milk for Pig and Calf Feeding.
Abstract, Exp. Sta. Record, Vol. 19,
p. 363.
207. Wilson, J., Curtiss, C.F., Kent, D.A., Patrick, G.E.
1891 Calf Feeding Experiments.
Iowa Agr. Exp. Sta. Bulletin 14.
208. Wing, H.H., Savage, E.S., Tailby, G.W., Jr.
1909 Substitutes for Skimmed Milk in
Raising Calves.
Cornell Univ. Agr. Exp. Sta.
Bulletin 269.
209. Wing, H.H., Savage, E.S., and Tailby, G.W., Jr.
1911 Substitutes for Skimmed Milk in
Raising Calves.
Cornell Univ. Agr. Exp. Sta.
Bulletin 304.
210. Wing, L.W., Jr.
1917 Milk Substitutes, Powdered Skim
Milk for Raising Calves.
Thesis for the degree A.M.,
University of Missouri.

211. Woll, F.W.
1915 Productive Feeding of Farm Animals.
 Philadelphia, Pa.
 J.B.Lippincott Co. (1915)
212. Woll, F.W. and Voorhies, E.C.
1916 Feeding Dairy Calves in California.
 California Agr. Exp. Sta. Bulletin
 271.
213. Woll, F.W. and Voorhies, E.C.
1916 Feeding Dairy Calves in California.
 Ibid. pp. 43-44.
214. Woodbury, C.G.
1917 Calf Feeding.
 Purdue Univ. Agr. Exp. Sta.
 Newspaper Bulletin 220.
215. Woodward, E.G.
1915 Raising the Dairy Calf.
 Nebraska Agr. Exp. Sta. Bulletin 149.
216. Woodward, T.E. and Lee, J.G., Jr.
1908 • Feeding Calves.
 Louisiana Agr. Exp. Sta. Bulletin
 104.

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COLUMBIA

COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
DEPARTMENT OF AGRICULTURAL CHEMISTRY

April 11th 1919.

Dean Walter Miller,
Graduate School,
211 Academic Hall.

My dear Dean Miller:

I have read the thesis submitted by
Milton H. Fohrman and it is my opinion that
it is a very excellent thesis and more than
meets the general standard that has been
established in the University for the Master's
dissertation.

Yours sincerely,

A handwritten signature in cursive script, reading "Robert Moulton". The signature is written in dark ink and is positioned above the typed name.

Professor Agricultural Chemistry.

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