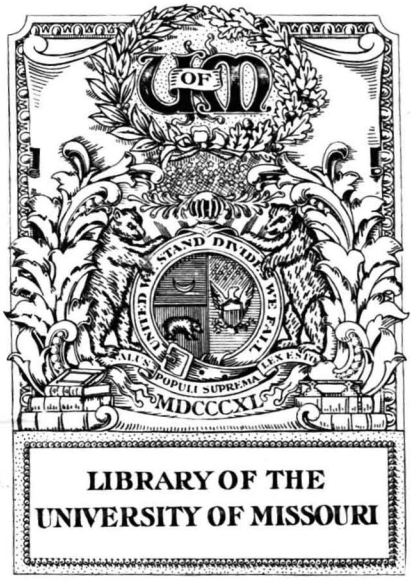

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MINIMUM PROTEIN REQUIREMENTS FOR THE GROWTH OF DAIRY HEIFERS

by

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SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS
in the

GRADUATE SCHOOL

of the

UNIVERSITY OF MISSOURI.

1915.

MINIMUM PROTEIN REQUIREMENTS FOR THE GROWTH OF DAIRY HEIFERS.

INTRODUCTION.

Considering the average productive life of a dairy cow to be eight years, there must be raised each year nearly 3,000,000 heifers in order to maintain the present number of dairy cows in this country. The raising of these heifers is an important economic problem to the dairyman and the cost of feeding them is by far the largest item. For a heifer until it is two years old, this feed cost has been found to be $40.83.[1] Of the feeds, those of a nitrogenous nature are the most expensive, especially to the farmer of the Middle West where corn is the most available feed. In order then, to reduce the feed cost as much as possible, it is of considerable importance to know the required amount

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1. U.S. Dept. Agr., Bul. No. 49.

of protein necessary to develop the heifer normally. There is no uniformity in the recommendations of the several feeding standards as to the proper amount of protein to be fed growing heifers and the results of investigations along these lines are at considerable variance. To best arrive at a protein standard for dairy heifers it would seem advisable to determine the minimum amount of this constituent necessary to promote their normal growth. With the object of determining such a figure, the Missouri Experiment Station started an experiment in August, 1913. The results of this experiment to date are given herein.

It has not been the intention to show the relative value of different rations. The practical value of the experiment will lie in the results obtained rather than in the methods used.

THE NATURE AND VALUE OF PROTEIN.

The substance or compound, protein, is commonly known as a necessary constituent of the food of all animals.

The Nature of Protein -- Protein is a complex organic compound made up of the elements carbon, oxygen, hydrogen, nitrogen, sulphur, and sometimes phosphorus. It is distinguished from the other food nutrients, carbohydrates and fats, chiefly by the fact that it contains nitrogen. "The name protein originated with Mulder, who used it to designate what he supposed to be a common ingredient of all the various proteids, but it has since come to be employed as a group name for the nitrogenous ingredients both of feeding stuffs and of the animal body."[1] "The proteins are very complex and usually amorphous compounds differing in composition and properties, but all of high molecular weight and unknown or incompletely known chemical structure, tho now regarded as essentially anhydrides of amino acids."[2] Formerly there was some con-

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1. Armsby, Principles of Animal Nutrition, pp 6-7.
2. Sherman, Chemistry of Food and Nutrition, p. 23.

fusion between the terms "proteins" and "proteids". A joint committee of the American Physiological Society and the American Society of Biological Chemists have recommended that the word "proteid" should be abandoned and that "the word "protein" should designate that group of substances which consist, so far as at present is known, essentially of combinations of a-amino acids and their derivatives."

The Value of Protein -- Proteins or protein substances are essential constituents of all living cells and therefore without them no life, either animal or vegetable, is possible. "They form the chief constituents of many of the fluids of the body, constitute the organic basis of animal tissue, and at the same time occupy a decidedly pre-eminent position among our organic food-stuffs. They are absolutely necessary to the uses of the animal organism for the continuance of life and they cannot be satisfactorily replaced in the diet of such an organism by any other dietary constituent either organic or inorganic."[1] In the diet of an animal "protein must be regarded simply as a suitable and convenient compound for the introduction of a certain amount of organized nitro-

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1. Hawk, Practical Physiological Chemistry, p. 60.

gen into the tissues.-----Protein is of importance to the tissues not because of any inherent virtue in itself but merely because it contains within its molecule certain compounds of nitrogen more or less ready for building purposes."[1]

PROTEIN METABOLISM.

Previous to 1867 "the theory advanced by Liebig was almost universally accepted. Liebig considered that the protein of the food was the one essential material, that it entered the organism without having undergone any very serious change during digestion, and that it immediately and directly replaced the effete material of the tissues[2]." Since that time a considerable definite knowledge has been gained concerning the digestion of protein and based on these known facts there have been advanced several theories regarding protein metabolism.

Briefly, the conceded facts concerning the digestion of protein are as follows: Protein digestion is essentially a process of cleavage and hydration under the influence of certain enzymes of

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1. Cathcart, Physiology of Protein Metabolism, p. 50
2. " " " " " p. 90.

the digestive tract. The protein of the food first comes in contact with the pepsin of the gastric juice which splits it into proteoses and peptones. The trypsin of the pancreatic juice acts on all forms of protein, which have passed on from the stomach, and reduces them to simpler products, proteoses, peptones, polypeptids, and amino acids. The erepsin of the intestinal juice acts on the simpler products and converts them into amino acids and ammonia.

The present generally accepted view as regards protein digestion and metabolism is that the protein of the food is split in the stomach and intestines into the crystalline amino acids. These are then absorbed as such by the blood and carried thruout the body. The animal proteins seem to contain the amino acids in definite proportions peculiar to themselves, and it must be assumed that the animal will require these same amino acids in the same proportions for repair. Thus it is believed that each tissue picks out the various amino acids in the correct proportion to build up its own special protein.

THE PROTEIN MINIMUM.

"The physioligical protein minimum is the quantity of protein which must be ingested in order to prevent loss of protein from the body." "As regards the uniformity of the protein minimum it may be definitely stated that there is no single minimum---common to all men and all conditions[1]." The factors which tend to make this minimum vary will be suggested but not all discussed. They are the caloric value of the diet, the nature of the food, the temperature, and the activity of the organism.

Of these factors, the one most commonly effecting the feeding of cattle is the nature of the food. Recent investigations concerning the nature and composition of individual proteins throw considerable light on this problem. The work of Osborne and Mendel is of particular importance in this respect.

The research of recent investigators has proven that each individual protein is made up of a series of amino acids. At the present time there have been isolated eighteen different amino acids.

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1. Cathcart, Physiology of Protein Metabolism, p. 66

These are crystalline compounds, the primary cleavage products of all proteins. In the synthesis of a protein, these amino acid fragments are linked together to form the complex protein molecule and they are thus termed the "building stones" of the proteins. Not all the amino acids are contained in every protein nor are they always found in the same proportion. The difference in individual proteins is in the number and proportions of the amino acids of which they are composed.

Feeding experiments with isolated proteins conducted by several investigators, notably Osborne and Mendel, indicate that the nutritive value of a protein is dependant upon its amino acid content, that certain of the amino acids are indispensible to the organism in maintaining the normal functions of growth and maintenance. "Evidence points to the fact that glycocoll, proline, and possibly arginine are not indispensible. Also it is clear that tyrosine and tryptophane are necessary amino acids." "Tryptophane is indispensible for maintenance and lysine for growth[1]".

If we assume that the animal must construct its tissue protein from the amino acid fragments fur-

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1. Osborne and Mendel, Jour. Biol. Chem. Vol. 17, p. 325.

nished by hydrolysis, it is obvious that deficiencies in quantity in these amino acid "building stones" or a lack of one or more of them must lead to serious nutritive disturbances. Abderhalden[1] maintains that so long as there is no evidence that amino acids can readily experience a transformation into one another in the organism, the extent of protein construction in the body must be limited by the amino acid which is present in the smallest relative amount in the ingested protein. If this is correct it follows that those food proteins which approach most nearly to the tissue proteins in their amino acid make-up should most easily support the protein needs of the animal. "Any protein containing less than the necessary amount of one amino acid will be insufficient and any excess of a particular amino acid over the definite proportion required will not be utilized but excreted as waste nitrogen. If a food protein does not yield the amino acids in the right proportion for tissue repair, then the minimum amount of the protein required by the animal is that quantity which will supply enough of the amino acid present in the smallest proportion. It will be seen that the nearer the protein ingested approaches the amino acid content of the tissue protein, the smaller becomes the amount of protein required."[2]

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1. Osborne and Mendel, Jour. Biol. Chem. Vol. 12, p.473-510
2. Wood, Trans. High & Agr. Soc. of Scot. XXIII, pp. 84-93

THE PROTEINS OF CATTLE FEEDS.

The importance which may come to be attached to the unique chemical constitution of the individual proteins of the food of domestic animals has been indicated by the work of recent investigators. The work has been carried on largely with small laboratory animals and the results may not apply to farm animals, especially ruminants, with digestive organs of greater size and of a different nature. The character of the proteins of all the common feeding stuffs is not at present known and the discussion will be limited to those feeds, the nature of the protein of which has a direct bearing on this problem.

Timothy Hay -- Altho timothy hay is widely used as a roughage, its protein content is so small that it would seem of little importance. The chemical nature of its protein has not been investigated. However, protein from such a source may be of considerable value in supplying an amino acid deficiency in the proteins of other feeding stuffs in the ration.

Alfalfa Hay -- Ames and Boltz[1] give the

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1. Ohio Exp. Sta. Bul. 247.

following figures as to the distribution of the total nitrogen of alfalfa hay:-

	Forms of Nitrogen:			Protein Nitrogen
	Total: %	Amine: %	Protein	Percent of Total
First cutting	3.03	1.01	2.02	66.66
Second cutting	2.43	.55	1.88	77.28

This table shows that from one-third to one-fourth of the total nitrogen of alfalfa hay is in the non-protein or amine form. There has been some difference of opinion among authorities as to the value of this non-protein nitrogen as a source of tissue nitrogen for animals. Armsby[1] considers it of value for maintenance but considers it advisable to ignore it in a computation of rations for productive purposes such as growth. Kellner and Strusiewicz[2] have shown that sheep given protein-poor rations gained in weight when the amide, asparagin, was added. The concensus of opinion seems to be that the amides, at least some, can be built into the protein tissues of the bodies of farm animals and the non-protein nitrogen is usually given full value with the protein nitrogen in estimating the total protein of alfalfa hay.

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1. Bureau of Animal Industry, Bul. 143, p. 88.
2. From Henry's Feeds and Feeding, p. 36.

Hart, Humphrey, and Morrison[1] report an experiment comparing the efficiency for growth of the total nitrogen from alfalfa hay and from the corn grain, which contains only traces of "amide nitrogen". Growing heifers were fed rations in which the protein was derived entirely from alfalfa hay or from corn. From their results they conclude that the utilization of nitrogen for growth was as efficient when the source was from alfalfa hay as when it came from the corn kernel. From the fact that there was no sudden increase or decrease in the nitrogen content of the urine or feces when the animals were suddenly changed from one ration to the other, they conclude that the "amide nitrogen" was being used in the same way as was the true protein nitrogen; that full value, for growth at least, can be given to the total nitrogen of alfalfa hay.

The amino acid make-up of the proteins of alfalfa hay has not been determined, so, at the present time, we are unable to state whether these proteins are "complete" or "incomplete" in this respect.

Corn -- Osborne[2] gives the following per-

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1. Jour. Biol. Chem. Vol. 13, pp 133-153.
2. Science, n. ser., Vol. 37, pp. 185-191.

centages of individual proteins in the maize kernel. These percentages are average and the figures would vary to some extent.

Zein	58 %
Globulins)	
)	
Albumins)	6 %
)	
Proteoses)	
Maize Glutelin	36 %

Some over half of the total protein of the corn kernel is "zein". This protein contains neither of the amino acids, lysine and tryptophane. In feeding experiments with rats, Osborne[1] found complete nutritive failure when zein was the only protein fed. Such a diet failed either to promote growth or maintain adult animals. Replacing varying parts of zein with other proteins containing the missing amino acids caused rats to regain lost weight. Thus the nutritive failure of zein is attributed to the lack of lysine and tryptophane. "Maize glutelin" yields all the amino acids commonly found in proteins in proportions corresponding to those yielded by the majority of vegetable and animal proteins. Maize glutelin proved exceptionally efficient for producing

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1. Science, n.ser., vol. 37, pp. 185-191.

growth. Equal parts of zein and maize glutelin produced growth though more slowly. "Corn gluten", which consists chiefly of zein and maize glutelin, proved capable of maintaining rats for some time.

Osborne emphasizes that the probable reason for the failure of swine to grow normally when fed corn alone lies in its large proportion of zein. He says: "The results here presented leave no doubt that the deficiency observed in the practical feeding of corn grain is explained largely, if not wholly, by the unique chemical constitution of zein which forms such a large part of its proteins[1]."

It would seem entirely possible that the other proteins of the corn grain might supply a sufficient amount of the amino acids which are absent from zein. Hart and McCollum[2] attempted to raise swine on a ration restricted to corn meal and gluten feed. No growth could be secured, but with an addition of salts, making the entire ash content of the ration very similar in quality to that of milk, growth approximating that of a normal curve was secured to at least 275 pounds. This is not in har-

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1. Science, n.ser., vol. 37, pp. 185-191.
2. Jour. Biol. Chem. Vol. 19, pp. 373-396.

mony with Osborne's theory that the failure to promote growth on corn alone is due to the incomplete nature of its protein content. Osborne, himself, in a later publication[1] modified his earlier view, quoted above, and expresses the possibility that the amino acid deficiency of zein may be supplied, in part at least, by the other proteins found in the corn kernel.

PROTEIN REQUIREMENTS OF GROWING CATTLE.

That the growing animal requires more protein per unit of live weight than does the mature animal is a conceded fact. For maintenance --- tissue repair and the performance of the vital functions of the body --- the young animal doubtless requires the same amount of protein in proportion to its size as does the mature animal. Besides this requirement, the growing animal demands protein for the performance of the function of growth, that is, for the building of new tissue.

A study of the literature along the line of protein requirements for growing dairy heifers reveals a wide variation in the results of different investiga-

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1. Jour. Biol. Chem. Vol. 18, p. 1.

tors. Feeding standards recommend varying amounts of protein to be fed. Unfortunately, much of the work on which these feeding standards were based was done with growing beef animals and not with animals of the dairy breeds.

The amount of digestible crude protein recommended by the Wolff-Lehmann[1] feeding standards for growing dairy heifers at different ages is given in the following table:-

Age in months	Weight: Lbs.	Lbs. Digestible Crude Protein	
		Per 1000 lbs. wt	Per Animal
2 - 3:	150	4.0	.60
3 - 6:	300	3.0	.90
6 - 12:	500	2.0	1.00
12 - 18:	700	1.8	1.26
18 - 24:	900	1.5	1.35

This table shows that, altho the heifer requires more protein as she grows older, the younger she is the more protein she requires per 1000 pounds live weight.

Armsby's[2] estimate as to the nutrients required per day by growing cattle is given in the fol-

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1. From Henry's Feeds and Feeding, p. 592, 1912 Edition.
2. Farmer's Bul. 346.

lowing table. In this table the protein is calculated from the true protein nitrogen and not from the total nitrogen.

Estimated Requirements Per Day and Head for Growing Cattle.

Age Months	Live Weight Lbs.	Digestible Protein Lbs.	Energy Value Therms
3	275	1.10	5.0
6	425	1.30	6.0
12	650	1.65	7.0
18	850	1.70	7.5
24	1000	1.75	8.0
30	1100	1.65	8.0

Armsby suggests that in using this table, the weight of an animal rather than its age should be considered.

The above estimate was made from results obtained from feeding trials with beef steers and the amount of protein would seem high when considered in connection with dairy heifers. These requirements are much higher than those given in the Wolff-Lehmann standard as a comparison of the two tables will indicate.

Kellner[1], in his standard rations, gives the following as the protein requirements of growing dairy cattle:

Age Months	Live Weight Lbs.	Digestible Protein, Lbs. Per 1000 Lbs.	Per Animal
2-3	150	3.4	.51
3-6	300	2.8	.84
6-12	500	2.3	1.15
12-18	700	1.8	1.26
18-24	900	1.3	1.17

The amounts called for by Kellner's standard are lower than either Armsby's or the Wolff-Lehmann requirements, yet a comparison of the tables shows that the Kellner standard differs only slightly from the Wolff-Lehmann.

Fingerling[2] conducted a series of metabolism experiments with four calves on different rations and concludes that 1.5 kilograms of digestible protein per day per 1000 kilograms live weight gives as satisfactory results for calves from five to nine months of age as a larger proportion of protein, provided there are sufficient carbohydrates in the ration. Cal-

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1. The Scientific Feeding of Animals, p. 392.
2. Landw. Vers. Stat. 76(1912) pp 1-74. From E.S.R. Vol. 26, p. 768.

culated for a 300 pound animal at six months of age, his estimate would allow for .45 pounds of protein per day.

Flint[1], of the Georgia Experiment Station, carried on an experiment to determine the protein requirements of growing cattle under one year of age. The animals used were of the dairy type with Jersey blood predominating. They were three to five months old when the experiment was started. During a preliminary period of 30 days each animal was fed according to the Wolff-Lehmann standard. The experiment consisted of two periods of 88 days each. The calves were divided into three lots. It was intended to feed Lot 2 the amount of protein called for by the standard and to feed Lot 1 25 percent less and Lot 3, 25 percent more protein than required by the standard. The carbohydrate and fat content of the rations was to be in all cases as called for by the standard.

The following table gives the results obtained during the two periods:

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1. Georgia Bul. 90.

First Period - Average for 88 Days.

Lot	Lbs. Av. Wt.	Lbs. Daily Gain	Digestible Protein, Pounds Per 1000 pounds	Digestible Protein, Pounds Per Animal
Lot 1:	223.5:	.79 :	2.15 :	.48 :
Lot 2:	198.9:	.82 :	3.02 :	.60 :
Lot 3:	216.1:	1.12 :	3.70 :	.80 :
Second Period - Average for 88 Days				
Lot 1:	291.1:	.78 :	1.86 :	.54 :
Lot 2:	280.9:	1.09 :	2.63 :	.74 :
Lot 3:	312.5:	1.27 :	3.23 :	1.01 :

The animals receiving the largest amount of protein made the best daily gains, and the amount of protein which they received conformed more nearly to the amount prescribed by the Wolff-Lehmann standard.

The nitrogen balance was determined on two animals from each lot. The results show that the calves receiving the largest amount of protein, while they made better gains, retained no more nitrogen than did the other animals. About the same amount of nitrogen was excreted in the feces regardless of the amount ingested. Thus the animals ingesting the larger amounts must have absorbed more, as his figures show.

But the greater ingestion nitrogen was accompanied by a much greater excretion in the urine so that there was a little difference in the amount retained. The author concludes from this that the smallest amount of protein, that received by Lot 1, was adequate for normal development.

Jordan[1], of the Maine Station, conducted an experiment with beef steers from the time they were about six months old until eighteen months old. Two lots of two steers each were used. One lot was fed a protein-rich ration and the other a protein-poor ration. As with many experiments conducted for the purpose of determining growth requirements for cattle, the animals used were the beef type and the results obtained cannot be considered as applying directly to dairy animals.

The following table gives the results obtained by Jordan:-

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1. Report of the Maine Experiment Sta., 1895, p. 51.

Period	No. Days	Approximate Age	Digestible Protein, Lbs		Daily Gains	
			Lot 1	Lot 2	Lot 1	Lot 2
1	91	6	.58	.44	1.16	.78
2	84	9	.89	.55	1.38	1.04
3	98	12	1.22	.77	1.88	1.67
4	98	15	1.22	.71	1.22	1.15
5	91	18	1.55	.85	1.36	1.12

Thruout the experiment, the steers receiving the protein-rich ration made the greater daily gains. However, the gains made by the steers on what Jordan evidently considered a protein-poor ration would be excellent for dairy heifers at corresponding ages. A comparison with the Wolff-Lehmann standard shows that the protein-rich ration was above, and the protein-poor ration was below, the requirements in protein content.

Skinner and Cochel[1] of Purdue, report an experiment to determine the influence of age on the economy and profit of fattening steers in winter. Again, the animals used were of the beef type. The amount of feed consumed is recorded and the nutrients have been calculated according to Henry's[2] tables. The

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1. Purdue University, Bul. 136.
2. Henry's Feeds and Feeding, 1912 Edition.

figures given below are of the first winter, carrying the animals from calves to about twelve months of age.

Average for Six Months.

Digestible Protein: Daily Pounds	Average Daily: Gains Pounds	Pounds Protein: per pound Gain
1.72	2.00	.86

The amount of protein fed in this experiment was even higher than than recommended in Armsyb's estimate. The daily gain was likewise higher than would be desirable with dairy heifers.

The Kansas Experiment Station[1] reports the feed consumed and the gains made by a number of growing cattle thru one winter. Most of the animals used were of the beef breeds or were bulls, but from the records given, those of four Jersey heifers have been selected and the amount of protein has been calculated by Henry's[2] tables. The

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1. Kansas Bulletin 72.
2. Henry's Feeds and Feeding, 1912 Edition.

heifers were nearly one year old when the experiment was begun. The period covered 147 days. The ration evidently contained a sufficient amount of energy value. The following table gives the average ages, weights, and daily gains for the period of 147 days, and the digestible protein fed daily.

Jersey Heifers

	Age in Months	Wt.	Digestible Protein Lbs.	Daily Gains
No. 4	13.86	603	.975	1.33
No. 5	14.69	575	1.185	1.15
No. 6	13.50	586	.948	1.27
No. 7	13.01	524	1.051	1.09
Average	13.76	572	1.040	1.21

The daily gain made by these heifers was excellent, probably somewhat above the normal gain for animals of this breed at this age. The amount of protein fed was very near to that required by the Wolff-Lehmann standard.

Many feeding experiments with growing cattle have been conducted besides the ones herein discussed. A large number of them were conducted

with animals of the beef breeds and in the reports of many it is impossible to calculate the nutrients fed daily or to determine the feed consumed at different ages. So far as we are able to determine, there has been no experiment conducted for the express purpose of determining the minimum amount of protein necessary to promote normal growth in dairy heifers. In the experiments of Flint[1] and Jordan[2], the effects of different planes of protein ingestion was studied but no attempt was made to determine the minimum figure.

In the table given below, the amounts of protein recommended by the different feeding standards have been tabulated, as well as the results obtained in the experiments discussed. The amounts for different ages are given and the weights for these ages are based on the normal weights as determined by Burlingham and Gillette[3] for Holstein and Jersey heifers. These figures are by no means directly comparable, and are not inserted for that purpose, but rather to emphasize the point already made that there is little or no uniformity in the amounts

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1. Loc. Cit.
2. Loc. Cit.
3. Thesis for Degree of M.A., University of Mo., 1914.

of protein recommended by the different feeding standards or the results obtained by different investigators.

Digestible Protein Daily, Pounds.

	Jerseys			Holsteins		
	6 Mos	12 mos	18 mos	6 Mos	12 mos	18 mos
Wolff-Lehmann	.795	.936	1.136	.963	1.041	1.278
Armsby	1.077	1.431	1.518	1.200	1.391	1.675
Kellner	.742	1.070	1.225	.836	1.098	1.278
Fingerling	.398			.525		
Flint (Low	.570			.753		
Flint (Medium	.800			1.057		
Flint (High	.981			1.295		
Jordan (Pro.-Poor*	.440	.770	.850	.440	.770	.850
Jordan (Pro.-Rich*	.580	1.220	1.550	.580	1.220	1.550
Purdue Station*		1.720			1.720	
Kansas Station		.851			.996	

*Calculated on age rather than weight.

EXPERIMENT.

Object -- The experiment herein discussed was conducted for the purpose of obtaining data from which it would be possible to determine the minimum amount of protein necessary to promote the normal growth of dairy heifers after six months of age.

Plan -- There seem to be two possible methods of solving this problem in an experimental way. One method would be to conduct a complete metabolism experiment for short periods to determine the amount of protein retained when different amounts are fed. The other method, and the one adopted, introduces the time factor and requires data on the protein ingestion and the development of the animal until it reaches maturity or practically so. By adopting the second method, it is possible to determine the effect of different planes of protein ingestion not only upon growth but also upon the age at which sexual maturity is reached and upon the ability of the animal to reproduce itself.

In this experiment it was planned to eliminate all factors with the exception of the amount of protein in the ration. The energy value of the

ration and its mineral content was to be sufficient. Under the above conditions, making the amount of protein ingested the only limiting factor, it was planned to feed different heifers varying amounts of protein from the time they were six months of age until sometime in their first lactation period.

Animals Used -- The animals used in the experiment have been purebred heifers from the University herd. Previous to six months of age they received the same care as all the calves in the herd. They were fed skim milk, alfalfa hay, and grain.

Analysis of Feed and Calculation of Nutrients -- All feeds used in the experiment were analysed by the Department of Agricultural Chemistry for total nitrogen, crude fibre, fat, nitrogen-free extract, and minerals. The amount of total protein was calculated from the total nitrogen by use of the factor 6.25. The digestible protein was calculated from the total protein by using Henry's[1] average digestion coefficients for the protein of the different feeds. The energy value of the rations was determined from the values of the different feeds given in

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1. Henry's Feeds and Feeding, 1912 Edition.

Armsby's[1] tables. In regulating the mineral content of the ration, the mineral analysis of the different feeds, as determined by the Chemistry Department, was used.

Feeding -- The animals were fed morning and evening. All feeds were weighed at each feeding and the amount recorded daily. Any feed not consumed was weighed back and the amount recorded.

General Care and Treatment -- Previous to the fall of 1914, the heifers were kept practically the full time in small box stalls with board floors. Shavings were supplied for bedding. In good weather they were allowed the run of a dry yard during the day. They were kept muzzled at all times when not in their stalls to preclude any possibility of obtaining feed and also because they showed a tendency to eat dirt. Since November, 1914, the heifers have been stabled in a barn built especially for experimental heifers. Each heifer had a single box stall with a cinder floor. Shavings only were used for bedding. During the greater part of the day, the animals were turned out in a dry yard and were kept muzzled while not in the barn. Clear fresh water was available at all

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1. Farmers' Bul. 346, U.S.Dept. Agri.

times when the animals were in the yard. A box in each stall was kept filled with salt.

Weighings and Measurements -- Until December, 1914, the heifers were weighed weekly. Once each month the animals were weighed on three consecutive days and the average for the three days taken as the weight for the middle day. Beginning in December, 1914, weights were taken every ten days and three-day weights every thirty days. The following measurements of the heifers were taken monthly. Not all of these measurements have been used but all are available.

1. Height at withers
2. Height at highest point of croup.
3. Height at hip points.
4. Depth of chest just behind elbow joint.
5. Width of chest just behind elbow joint.
6. Width of hips
7. Width of loins
8. Length from poll to point of muzzle.
9. Width of forehead.
10. Circumference of muzzle at opening of mouth.
11. Length from base of horns to withers.
12. From highest point of withers to line between hips.

13. From a line between hips to tail.
14. From point of shoulder to point of hips
15. From point of shoulder to ischium.
16. From point of hip to ischium.
17. From point of hip directly forward to last rib.
18. Heart girth just behind elbow joint.
19. Girth of paunch at end of last rib.
20. Smallest circumference of shin-bone of fore leg.
21. Smallest circumference of shin-bone of hind leg.

Discussion of No. 91 and No. 94.

Condition at Beginning of Experiment -- The first animals used in this experiment were two pure bred Jersey heifers, No. 91 and No. 94. No. 91 was born January 27, 1913, and was 6 months and 15 days old on August 11, when the experiment was begun. No. 94 was born February 7, 1913, and was 6 months and 4 days old on August 11. Both heifers were in good condition. No. 91, altho older than No. 94 was not so heavy. On August 11, No. 91 weighed 216 pounds and No. 94 weighed 235 pounds. No. 91

was a small calf at birth which accounts for her small size at 6 months. No. 94 was very near the normal weight for Jerseys at 6 months. Plates I and II illustrate the condition of the heifers at the beginning of the experiment.

Plan of Feeding No. 91 and No. 94. -- It was planned to feed No. 91 a high protein ration and No. 94 a low protein ration. At the same time it was planned to keep the energy value of the two rations practically the same and high enough to insure against the possibility of its entering in as a factor in hindering growth and development. No attempt was made, in feeding either heifer, to meet any feeding standard or to feed any proportionate amount of the protein called for by such standards. No. 91 was to be fed what was believed to be a sufficient amount of protein and No. 94 was to be fed what was likewise believed to be an extremely low amount of protein.

Rations Fed -- No. 91 was fed alfalfa hay as a roughage and No. 94 was fed timothy hay. No. 91 received a grain mixture of corn, bran, and cottonseed meal during the first half of the experiment.

The cottonseed meal and bran were later left out of the ration and the heifer received corn alone with alfalfa hay. No. 94 received corn only with timothy hay. On January 21, 1915, the ration of No. 94 was changed to alfalfa hay, timothy hay, and starch and sugar. The reasons for this change will be discussed later.

EXPERIMENTAL DATA.

Tables 1 and 2 give the average daily consumption of the diffferent feeds, by 28 day periods, for No. 91 and No. 94.

Table 3 gives the analysis of the feeds used.

Table 4 gives the grams of calcium and phosphorus in the daily ration for four representative periods.

Table 5 gives the average by 28 day periods of the nutrients received daily by the two heifers. The method of calculation has been described. The calorie value of the starch and sugar mixture fed No. 94 during Periods 20-22 was determined from the calorie value of the pure nutrients.[1] The weights given are the average of the weekly weights during the period.

Table 6 gives the weights and measurements of the two heifers by 28 day periods. In determining the wither heights, the average of three different measurements at this point were taken.

Table 7 gives the average daily gain by periods and the pounds of digestible protein and the therms of energy value per pound of gain.

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1. Bul. No. 71, Penn. Exp. Sta.

Chart 1. The curves of Chart 1 show the energy value in therms which the heifers received daily by periods. The curve showing Armsby's standard is determined from the weights of No. 91, by periods.

Chart II. -- The curves in Chart II show the pounds of digestible protein consumed daily by periods. The curve for the Wolff-Lehmann standard is determined from the weights of No. 91.

Chart III --gives the curves of weights by periods of the heifers and the curve of normal weight for Jerseys until 24 months old.

Chart IV gives the curves of height at withers by periods and the curve of normal height for Jerseys.

Chart V -- The curves in Chart V show the relation between the daily ingestion of nutrients and the increase in height and weight of No. 91. The curves are drawn to the same scale as in the preceding charts.

Chart VI represents the same relation for No. 94 as does Chart V for No. 91.

TABLE 1.

FEED CONSUMED DAILY

AVERAGE BY 28 DAY PERIODS.

No. 91 - High Protein.

Period	Alfalfa Pounds	Corn Pounds	Bran Pounds	Cottonseed Meal Pounds
1	3.30	1.33	1.00	.66
2	3.77	1.52	1.14	.76
3	4.77	1.92	1.44	.96
4	5.50	2.22	1.66	1.11
5	5.50	2.22	1.66	1.11
6	5.50	2.22	1.66	1.11
7	5.50	2.22	1.66	1.11
8	5.79	2.39	1.79	1.19
9	5.08	2.06	1.55	1.03
10	5.50	2.22	1.66	1.11
11	5.50	3.24	1.29	.47
12	5.46	4.00	1.00	
13	5.50	4.00	1.00	
14	5.09	4.00	1.00	
15	5.50	4.00	1.00	
16	5.50	4.00	1.00	
17	6.00	4.80	.50	
18	6.50	5.60		
19	6.50	5.60		
20	6.50	5.60		
21	6.50	4.51		
22	6.50	4.00		

TABLE 2.

FEED CONSUMED DAILY

AVERAGE BY 28 DAY PERIODS.

No. 94 - Low Protein.

Period	Timothy Lbs.	Corn Lbs.	Alfalfa Lbs.	Starch Sugar* Lbs.	Bone Meal Grams	$CaCO_3$ Grams
1	2.94	3.72				
2	3.34	4.23				
3	3.96	4.98				
4	3.62	4.73				15
5	3.60	4.50			10	20
6	3.69	4.63			40	20
7	3.60	4.50			40	20
8	4.24	5.30			40	20
9	4.11	5.14			40	20
10	4.40	5.50			40	20
11	4.34	5.25			40	20
12	3.61	5.00			47	22
13	2.91	5.06			60	25
14	3.70	5.20			60	25
15	4.00	5.20			60	25
16	4.00	5.20			60	25
17	4.50	5.70			60	25
18	5.00	6.20			60	25
19	5.00	6.20			60	25
20	1.04	.96	4.93	3.45	6	3
21	.50		5.73	4.05		
22	2.00		4.00	3.60		

*Mixture of 11 pounds corn starch to 3 pounds sugar.

TABLE 3.

NITROGEN AND MINERAL CONTENT OF FEEDS.

Feed	Lot	Percent nitrogen	Percent Calcium	Percent Phosphorus	Percent Magnesium	Percent Potassium	Periods Fed
Corn	5	1.469	.010	.266	.081	.141	1-15 inc
Corn	6	1.614					16-22 "
Timothy	1	.583	.148	.126	.067	1.243	1-22 "
Alfalfa	5	1.840	1.059	.310	.182	1.180	1-16 "
Alfalfa	6	2.944					18-22* "
Bran	3	2.102	.153	1.428	.460	.873	1-15 "
Bran	4	2.994					16-17 "
Cotton-S.Meal	4	6.323	.157	.758	.101	.686	1-11 "
Bone Meal	1	1.070	24.070	12.440			5-15 "
Bone Meal	2	1.566					16-20 "

*Period 17 - Alfalfa, Lot 5, 90 pounds.
" Lot 6, 78 pounds.

TABLE 4.

CALCIUM AND PHOSPHORUS IN DAILY RATION

Period	Calcium Grams		Phosphorus Grams	
	No. 91	No. 94	No. 91	No. 94
1	17.097	2.147	15.031	6.182
6	28.495	20.315	25.050	12.671
18	31.506	28.083	15.911	17.814
22	31.434	20.576	13.978	6.772

TABLE 5.

NUTRIENTS RECEIVED DAILY

AVERAGE BY 28 DAY PERIODS.

No. 91 - High Protein

No. 94 - Low Protein.

Period	Age - Days Beginning of Period		Weight Average for Period		Digestible Protein Pounds		Energy Value Therms	
	No. 91	No. 94	No. 91	No. 94	No. 91	No. 94	No. 91	No. 94
1	196	185	219	254	.686	.311	3.354	4.292
2	217	206	252	283	.784	.354	3.837	4.879
3	245	234	291	306	.989	.417	4.849	5.753
4	273	262	323	329	1.143	.393	5.601	5.316
5	301	290	350	329	1.143	.378	5.601	5.206
6	329	318	389	343	1.143	.393	5.601	5.351
7	357	346	408	364	1.143	.383	5.601	5.206
8	385	374	421	384	1.219	.450	5.980	6.132
9	413	402	450	406	1.059	.437	5.293	5.945
10	441	430	481	435	1.143	.467	5.601	6.363
11	469	458	501	439	.967	.448	5.789	6.121
12	497	486	520	436	.832	.419	5.914	5.653
13	525	514	550	445	.836	.413	5.929	5.472
14	553	542	567	459	.802	.436	5.787	5.862
15	581	570	582	473	.836	.442	5.929	5.962
16	609	598	602	476	.906	.482	5.929	5.962
17	637	626	614	483	1.075	.529	6.570	6.574
18	665	654	637	501	1.290	.576	7.212	7.186
19	693	682	677	533	1.290	.576	7.212	7.186
20	721	710	685	552	1.290	.745	7.212	6.403
21	749	738	702	581	1.207	.76 7	6.244	6.255
22	777	766	727	617	1.168	.565	5.791	5.705

TABLE 6.

WEIGHTS AND MEASUREMENTS

BY 28 DAY PERIODS.

Period	Weight Pounds		Height at Withers Centimeters		Width of Hips Centimeters		Heart Girth Centimeters	
	No. 91	No.94	No.91	No.94	No.91	No.94	No.91	No.94
1	219	254	92.0	97.0	27.3	26.5	106.0	113.0
2	252	283	94.0	98.5	27.8	27.8	111.5	113.5
3	291	306	97.5	99.5	29.8	28.8	119.0	118.0
4	323	329	99.5	101.0	32.5	30.3	123.0	121.0
5	350	329	102.8	103.8	33.5	31.0	125.0	122.0
6	389	343	105.0	105.5	34.3	31.8	131.5	125.0
7	408	364	106.5	106.0	36.0	33.0	132.5	125.0
8	421	384	107.3	106.5	36.0	32.8	134.0	127.0
9	450	406	108.0	107.3	36.0	33.5	135.5	129.0
10	481	435	108.8	109.8	36.5	32.5	138.0	133.0
11	501	439	109.0	109.8	37.8	32.3	144.0	138.5
12	520	436	111.0	110.5	39.0	32.3	146.0	138.5
13	550	445	113.3	112.0	40.0	30.0	147.0	144.0
14	567	459	115.0	113.0	41.0	30.5	149.0	144.0
15	582	473	115.8	114.3	41.5	30.5	151.0	144.0
16	602	476	117.5	115.5	43.0	30.5	154.0	145.0
17	614	483	117.5	115.8	43.0	30.5	156.0	146.0
18	637	501	118.5	116.0	43.0	30.5	157.0	147.0
19	677	533	119.8	117.5	43.0	31.0	157.0	148.0
20	685	552	119.8	119.4	44.0	34.0	161.0	149.0
21	702	581	120.3	119.4	45.0	34.8	161.0	149.0
22	727	612	120.8	119.5	45.0	35.0	161.0	150.0

TABLE 7.

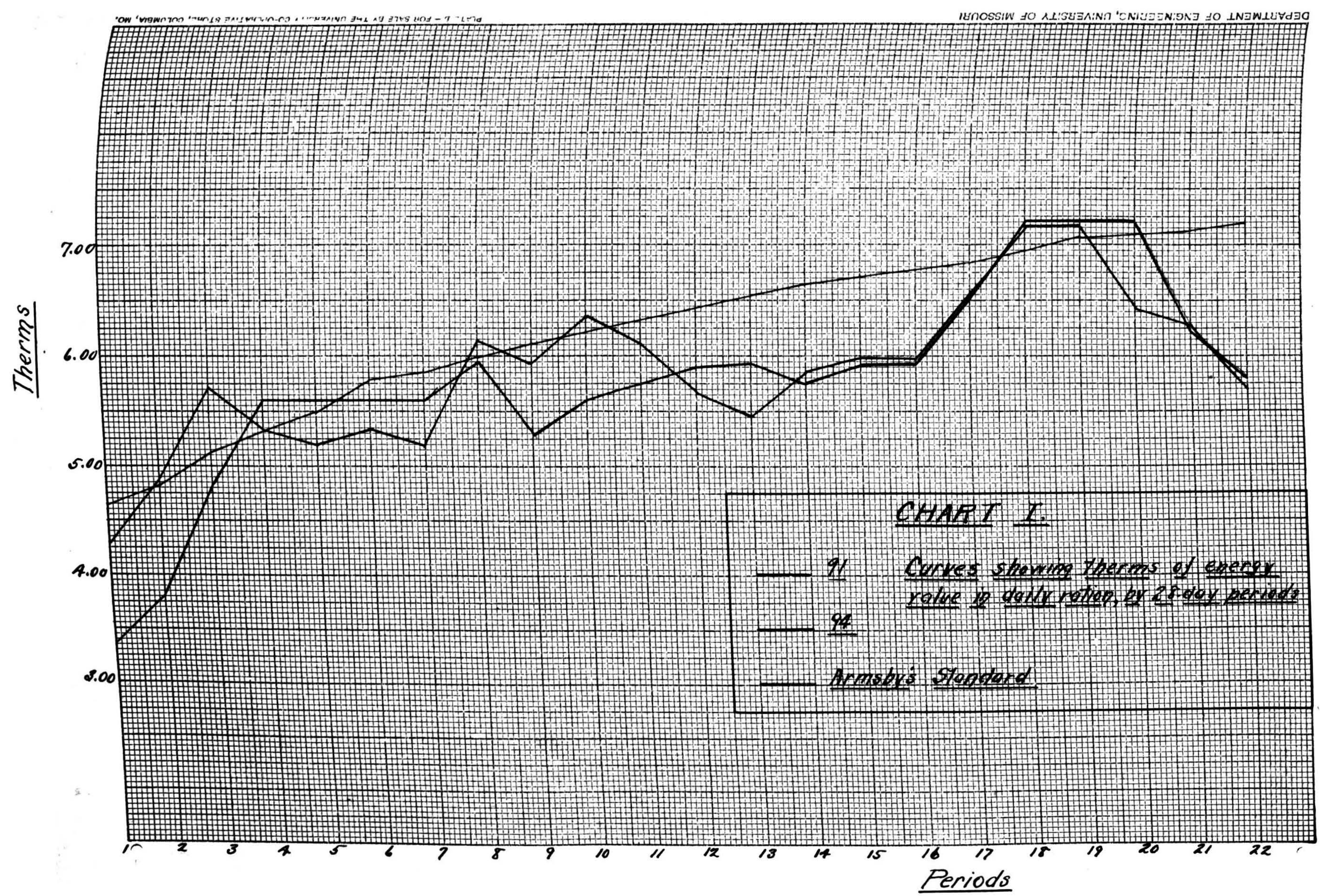
AVERAGE DAILY GAINS BY 28 DAY PERIODS

and

DIGESTIBLE PROTEIN AND ENERGY USED PER POUND OF GAIN.

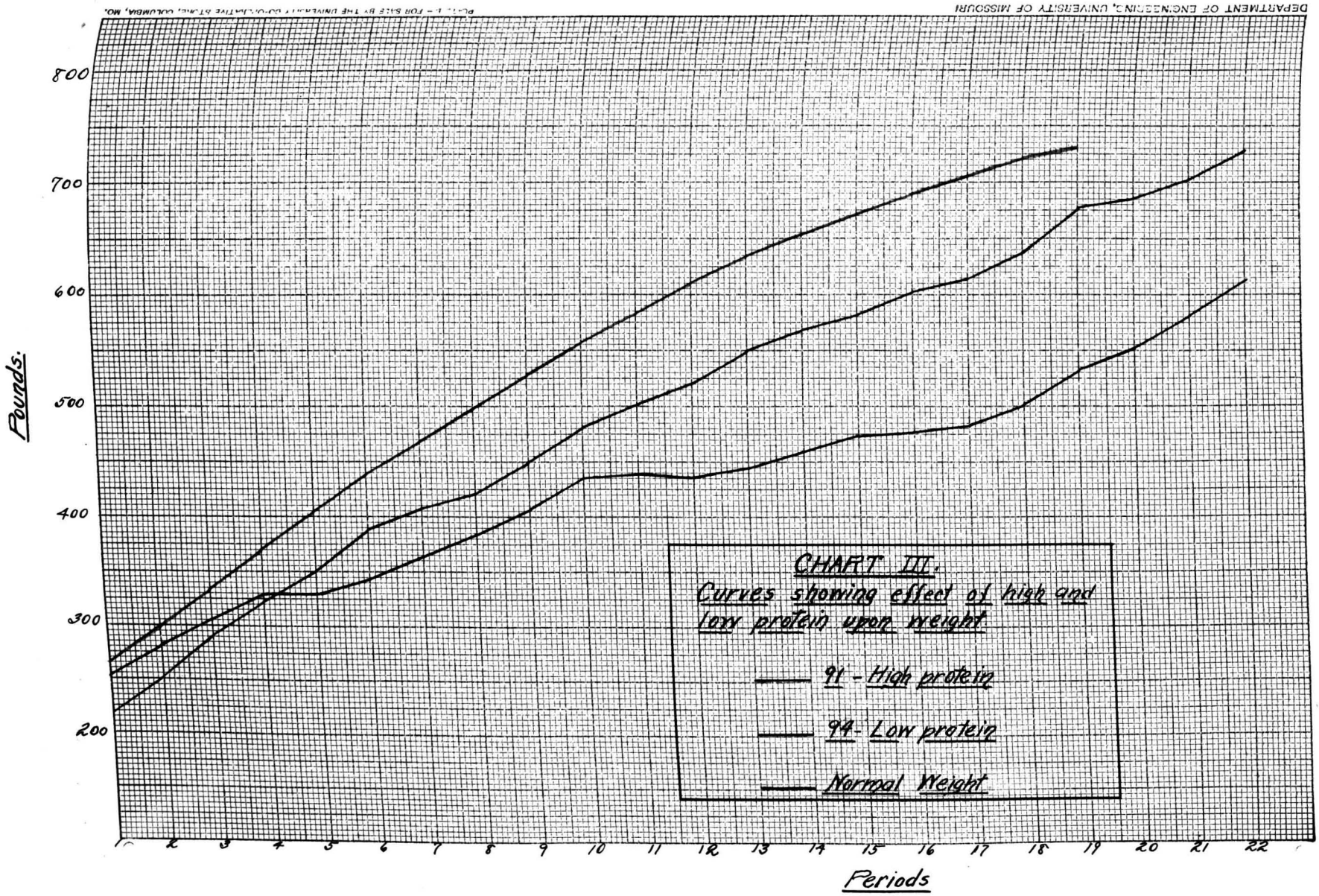
Period	Average Daily Gain for Period		Pounds Protein Per Pound Gain		Therms of energy Value per Pound Gain	
	No. 91	No. 94	No. 91	No. 94	No. 91	No. 94
1	.90	1.76	.76	.18	3.62	2.44
2	1.32	.86	.59	.41	2.91	5.67
3	1.14	.79	.87	.53	4.25	7.26
4	1.21	.39	.94	1.08	4.63	12.63
*Av.	1.16	.90	.79	.42	3.85	5.65
5	1.04	.14	1.10	2.70	5.39	37.19
6	1.14	1.21	1.00	.32	4.91	4.42
7	.61	.25	1.87	1.53	9.18	20.82
8	.67	.61	1.82	.74	8.93	10.05
9	1.11	1.11	.95	.39	4.77	5.36
10	.93	.71	1.23	.66	6.02	8.96
Av.	.91	.67	1.25	.62	6.16	8.51
11	.79	Loss	1.22	Loss	7.33	Loss
12	.93	.46	.89	.91	6.36	12.29
13	.67	.46	1.25	.90	8.85	11.90
14	.54	.50	1.49	.87	10.72	11.72
15	.57	.29	1.47	1.53	10.40	20.56
16	.75	.29	1.21	1.66	7.91	20.56
Av.	.70	.24	1.23	1.80	8.40	24.33
17	.36	.07	2.99	7.56	18.26	93.86
18	1.57	1.00	.82	.58	4.59	7.19
19	.50	.89	2.58	.65	14.42	8.07
20	.54	1.11	2.20	.67	13.36	5.77
21	.68	1.00	1.78	.78	9.18	6.26
22	1.07	1.29	1.09	.44	5.41	4.42
Av.	.79	.89	1.55	.68	8.49	7.36

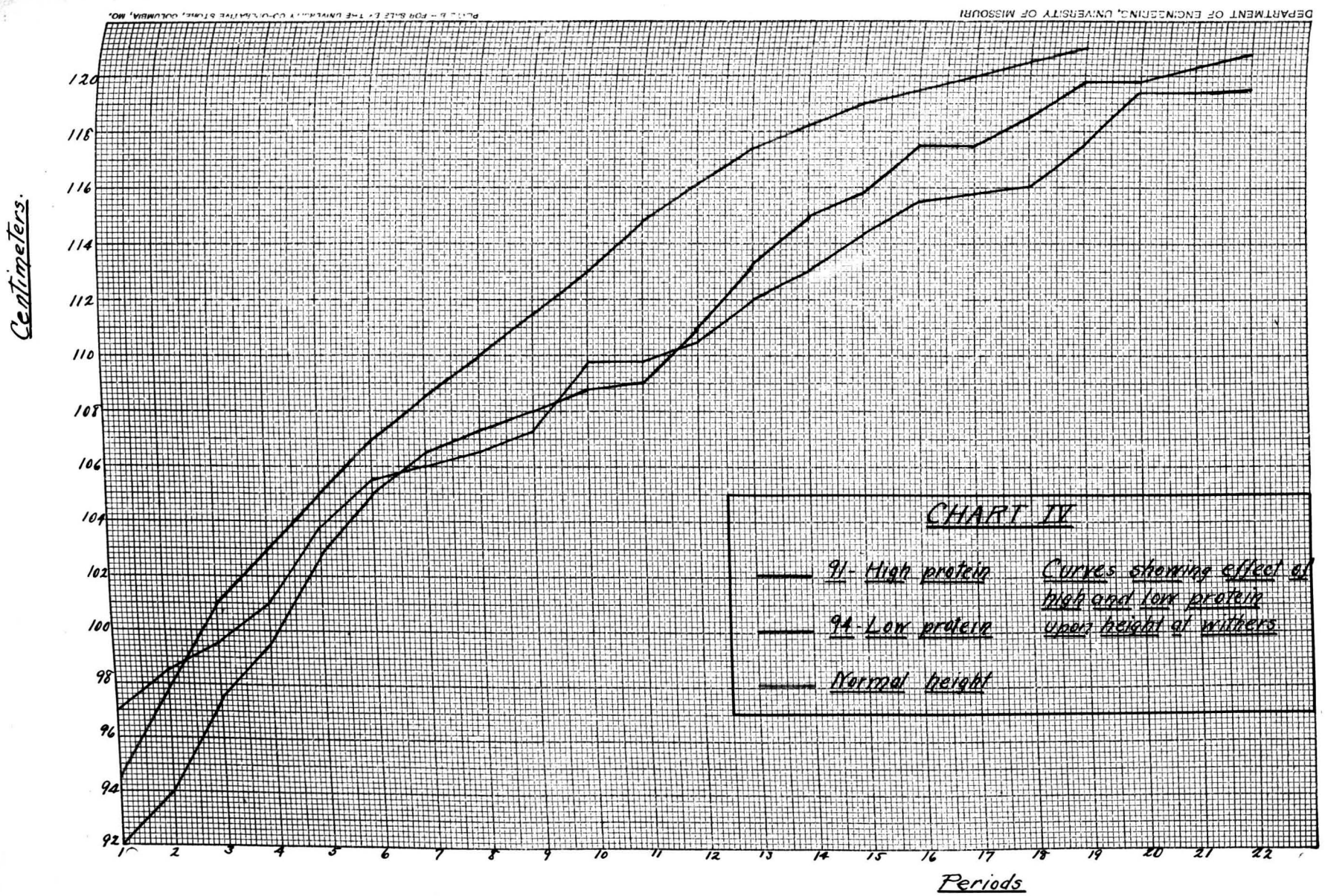
*Average determined by dividing total protein and energy for four periods by total gain.



DEPARTMENT OF ENGINEERING, UNIVERSITY OF MISSOURI
CHART I.
Curves showing Therms of energy value in daily ration, by 28 day periods
91
94
Armsby's Standard
Therms
7.00
6.00
5.00
4.00
3.00
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Periods

DEPARTMENT OF ENGINEERING, UNIVERSITY OF MISSOURI
CHART II.
91
94
Wolff-Lehmann Standard.
Curves showing digestible protein in daily ration, by 28 day periods.
Pounds
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Periods


DEPARTMENT OF ENGINEERING, UNIVERSITY OF MISSOURI
PLATE I. – FOR SALE BY THE UNIVERSITY CO-OPERATIVE STORE, COLUMBIA, MO.
Pounds.
800
700
600
500
400
300
200
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Periods
CHART III.
Curves showing effect of high and low protein upon weight
91 - High protein
94 - Low protein
Normal Weight


DEPARTMENT OF ENGINEERING, UNIVERSITY OF MISSOURI
PLATE B – FOR SALE BY THE UNIVERSITY CO-OPERATIVE STORE, COLUMBIA, MO.
Centimeters.
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Periods
CHART IV
91- High protein
94- Low protein
Normal height
Curves showing effect of high and low protein upon height of withers.

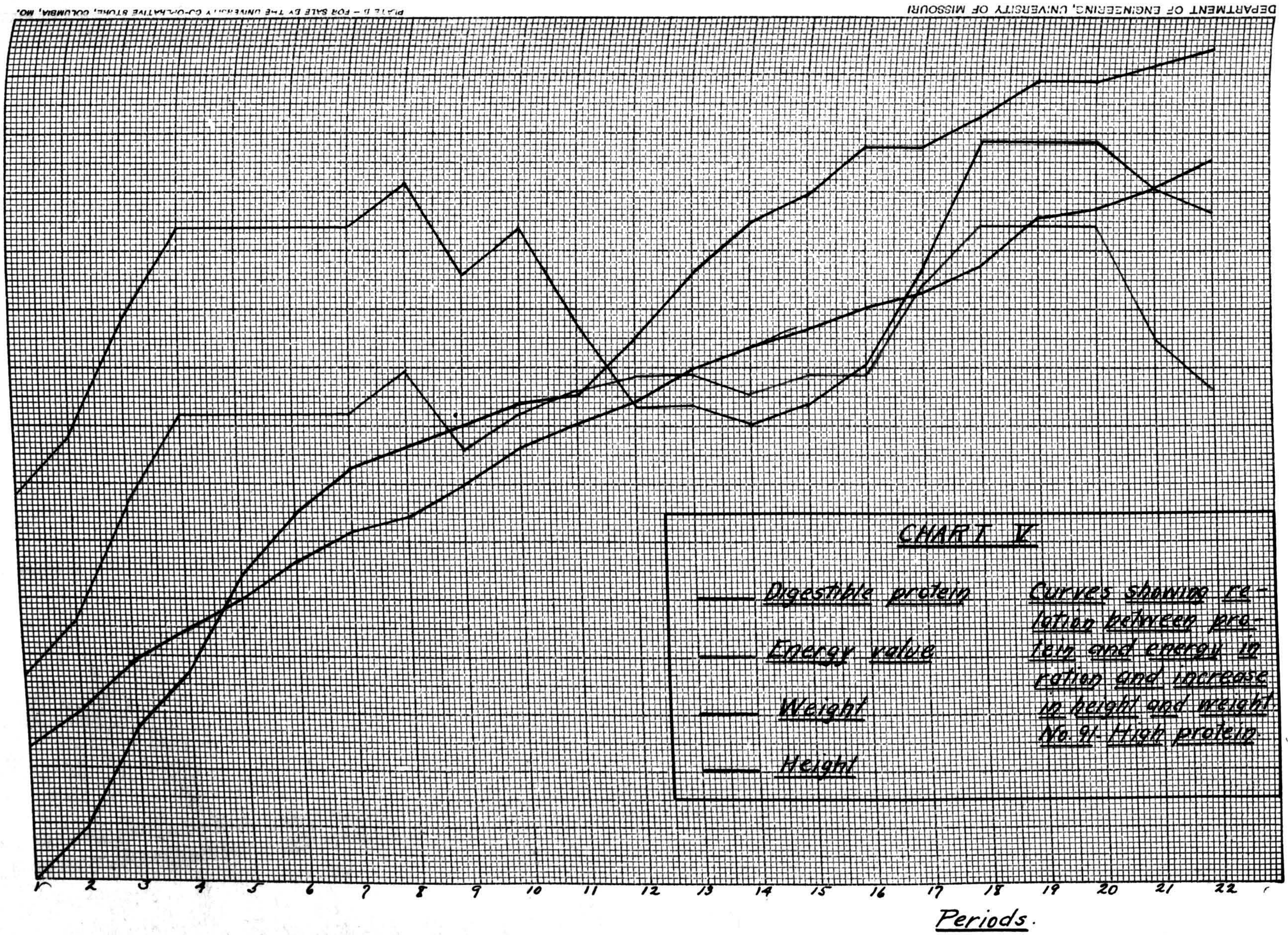


CHART V
Digestible protein
Energy value
Weight
Height
Curves showing relation between protein and energy in ration and increase in height and weight
No. 91- High protein.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Periods.
DEPARTMENT OF ENGINEERING, UNIVERSITY OF MISSOURI
PLATE B – FOR SALE BY THE UNIVERSITY CO-OPERATIVE STORE, COLUMBIA, MO.

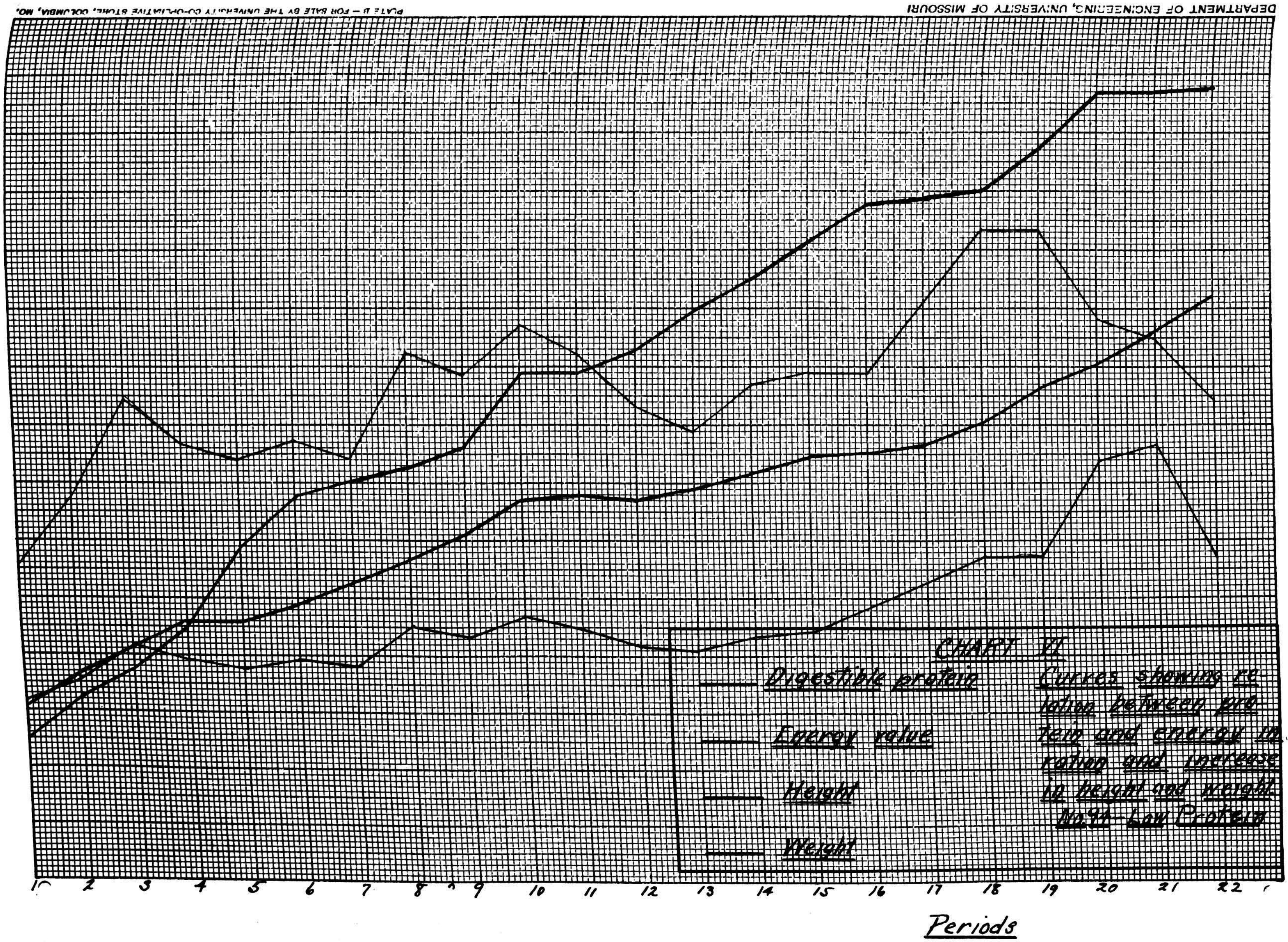


CHART VI
Digestible protein
Energy value
Height
Weight
Curves showing relation between protein and energy in ration and increase in height and weight. No 94 Low Protein
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Periods

Discussion of Data

In a feeding experiment to determine the effect of one factor upon growth, it is obviously essential that all other factors effecting the development of the animal be eliminated. Concerning this experiment, in which it was intended to make the amount of protein ingested the only limiting factor, the question arises, have conditions been so controlled as to insure the elimination of all other factors.

Our present knowledge would indicate the following as possible factors in the ration limiting the growth and development of a heifer.

1. Amount of protein in the ration.
2. Mineral content of the ration.
3. Energy value of the ration.
4. Quality of the protein.

In order to determine the minimum amount of protein for growing heifers, it is necessary to eliminate the last three of the above factors. A discussion of some of the preceding data will show whether any of these three have been possible limiting factors in this case.

Mineral Content of the Ration -- It will be seen from Table 4 that, during the first period, the calcium and phosphorus content of the ration of No. 94 was far below that of No. 91. This same condition held thru the first three periods. There is no question that, had this low mineral content of the ration continued for a long time, serious difficulties would have arisen. Beginning in Period 4, the heifer was fed $CaCO_3$, and in Period 5 bone meal was added. The calcium and phosphorus thus supplied in inorganic form made the two rations nearer equal in content of these elements. In Period 13 the amount of $CaCO_3$ and bone meal was increased, thus making the calcium content of the ration of No. 94 nearly equal to that of No. 91 and making the phosphorus content higher. No definite knowledge is available concerning the exact mineral requirements of growing heifers. There can be no question that the mineral content of the ration of No. 91 was more than sufficient in every way. If calcium and phosphorus supplied in inorganic form are as available to the animal as when supplied in organic combination, it would seem that a lack of these elements could not have been a limiting factor in the development of No. 94. The reason for the

change in the ration of No. 94 in January, 1915, was in part to supply calcium and phosphorus in organic form. This change and the effect thereof will be discussed more fully in another place. From lack of evidence as to the exact mineral requirements of heifers and the availability of inorganic calcium and phosphorus, we are not prepared to state that the mineral content of the ration of No. 94 was entirely eliminated as a factor.

Energy Value of the Ration -- A study of Table 5 and of Chart 1 shows that there was but little difference in the energy value of the two rations. Chart 1 shows that both rations were lower in energy value than Armsby's standard. However, Armsby's standard is intended for growing beef cattle and is probably high for dairy heifers. From Charts 5 and 6, it is evident that variations in the energy value of the rations bore no direct relation to the rate of increase in height or weight of the two heifers. There is little doubt that No. 91 received a sufficient amount of energy value in her ration. No. 94 received as much, at least, as did No. 91. These facts lead us to the conclusion that the energy value of the ration of No. 94 could not have been a limiting factor.

Quality of Protein -- From Table 2 it will be seen that, until Period 20, the ration of No. 94 was composed solely of timothy hay and corn. The protein content of timothy hay is low and the chief source of protein for the heifer was corn. About 75 percent of the total protein of the ration was derived from this source. The incomplete protein, zein, comprises over 50 percent of the protein of the corn grain. The work of Osborne and Mendel has demonstrated the complete nutritive failure which arises when zein alone is fed as the only source of protein in the ration. Since 75 percent of the protein of the ration of No. 94 was derived from corn and since over 50 percent of the protein of corn is zein, then this incomplete protein comprised about 40 percent of the total protein which the heifer received.

During the period when the heifer received corn and timothy hay, the quality of the protein supplied was approximately as follows:

a. 40 percent as the incomplete protein, zein, known to be inefficient due to its lack of the amino acids, lysine and tryptophane.

b. 25 percent as the protein of timothy hay, the amino acid make-up of which is not known.

c. 35 percent as the maize glutelin, globulins, albumins, and proteoses of the corn grain, all of which are known to be complete proteins and which have been proven efficient for the promotion of growth.

There is no evidence to warrant the conclusion that the amino acids lacking in the zein may have been sufficiently supplied in the remaining 60 percent of the total protein. The possibility that the quality of protein may have been a limiting factor must be admitted.

The Amount of Protein as the Limiting Factor.

For the purpose of discussion, it will be assumed that other factors were eliminated and that the amount of protein in the ration was the only limiting factor.

The Amount of Protein as a Factor in the Ration of No. 91 -- As previously stated, No. 91 was fed what was believed to be a sufficient amount of

protein. A study of Table 5 and of Chart II shows that the amount of protein which the heifer received fluctuated to a considerable degree thru the 22 periods. From Chart II, it will be seen that, for a large part of the time, she received protein in excess of the Wolff-Lehmann Standard. From Period 11 to Period 17, the amount of protein was noticeably below the standard. In Period 14, the protein ingestion was at the lowest point in proportion to the size of the animal.

It would seem unreasonable to question the adequacy of the amount of protein received by No. 91 during those periods when this amount was in excess of the Wolff-Lehmann requirements. If, however, the amount of protein was insufficient during those periods when it was below the standard, the relative rate of increase in weight and height during the periods of low and high intake should reveal this fact.

A study of the weight curves in Chart III shows that during Periods 11 to 17, or during the time of low protein intake, the curve for No. 91 was farthest from the normal. However, this lag in the rate of increase began in Period 6 and con-

tinued thru several periods of the highest protein intake. The curve for height at withers in Chart IV shows that the periods of low protein intake for No. 91 were marked by the most rapid increase in height. At this time, the curve was rapidly approaching the normal. Chart V, also, illustrates the fact that there was no relation between protein intake and increase in height, and little if any between amount of protein and increase in weight. While there were variations from the normal during intervening periods, both the height and weight of the heifer were approximately in the same relation to the normal at 27 months as at 6 months.

The photographs of No. 91, taken at different periods thruout the experiment, illustrate the excellent condition which the animal evidenced at all times. She was always active and in good spirits. Her coat showed the smooth sleek appearance characteristic of an animal in excellent condition. After she was 18 months old she became unusually fat for a dairy heifer. Her "blocky" appearance and tendency to fatten was probably an inherited characteristic since the same tendency was shown by her mother.

Plate III is a photograph of the heifer taken during Period 10 after several months of high protein intake. Plate V is a photograph taken during Period 14 at the time of the lowest protein intake. Any difference in the condition of the animal, judging from the photographs, is certainly in favor of the later date.

From the foregoing evidence, we are led to the conclusion that the amount of protein in the ration of No. 91 was entirely sufficient.

The Amount of Protein as a Factor in the Ration of No. 94 -- A study of Table 5 and of Chart II shows that the amount of protein in the ration of No. 94 was kept at a very low figure. This heifer received from one-third to one-half the amount fed No. 91 and at all times the amount was far below the Wolff-Lehmann requirements. The protein content of the ration varied but slightly. The sharp rise in the curve during Periods 20 and 21 is explained by the fact that the nitrogen content of the alfalfa hay fed during those periods was unusually high. An analysis was not available at the time and the amount of hay fed was regulated by an average of analyses. Up to Period 17, when she was 21 months old, the heifer received less

than half a pound of digestible protein daily. At this time the amount was increased slightly but with the exception of the two periods mentioned above the heifer never received as much as 0.6 of a pound daily.

From a study of Charts III and IV, it is at once evident that the heifer did not develop normally. At six months of age she was very near the normal weight for Jerseys, but from that time until Period 18, her weight relative to the normal showed a continual decrease. Her height at withers, at the beginning of the experiment, was considerably above normal but from that time on there was a check in the rate of growth and until Period 18, with the exception of scattered periods, this retarded rate of increase in height is evident. Assuming normal development, the heifer should have weighed 208 pounds more at Period 18. Likewise she should have shown a greater height at withers of 7 centimeters.

A study of the data shows that growth in height was much less retarded than increase in weight. Assuming, again, that the heifer had developed normally, she should have shown a gain in

weight, during the 18 periods, of 455 pounds while she actually gained but 247 pounds. Likewise she should have increased in height 26 centimeters while her actual increase was 19 centimeters. In other words, her increase in height was 73 percent of the normal while she gained in weight but 54 percent of the normal. Here we find a striking illustration of the strong tendency of the young animal to grow normally on a restricted ration even at the expense of a normal increase in body weight.

Plate IV is a photograph of the heifer during Period 14 and illustrates to some extent the very noticeable lack of developement which was evident after the first few months on the low protein ration. This lack of development was most apparent in the pelvic region and in the hind quarters. There was a marked lack of muscular development. The tail head was strikingly low, as well as coarse and rough from lack of flesh covering. The most noticeable defect, which gave the animal an almost deformed appearance, was the failure to grow normally in width of hips. The

lack of development in this region is shown by the width of hip measurements given in Table 6. The general appearance of the animal was rough and illkept and this was especially noticeable in cold weather. With the exception of a few brief periods, she showed a good appetite and consumed all her feed. On May 5, 1914, when she was 15 months old, the heifer came in heat for the first time and at regular intervals thereafter. She was bred September 27, 1914, and is carrying her calf at this writing. On April 2, 1914, the animal became totally blind. No explanation for this will be attempted.

It is very clear, from the data presented and from the preceding discussion, that No. 94, up to Period 18, did not develop normally in weight or skeletal growth. As previously stated, it is entirely possible that the mineral content of the ration and the quality of the protein may have entered in as factors in hindering the normal development of this animal, but the evidence is in favor of the conclusion that the amount of protein in the ration was too low and that this low protein ingestion was a strong limiting factor.

Thus far in the discussion, the development of the heifer after Period 17 has not been considered. From Charts III and IV it will be seen that the weight curve, after Period 17, and the height curve, after Period 18, were both approaching the normal. Since the change in the ration, as shown by Table 2, did not occur until in Period 20, the increased rate of growth cannot be attributed to this change of feed or to the high protein and minerals supplied in organic form resulting therefrom. There seem to be two possible explanations. From Period 15 to Period 18, there was a gradual increase in the daily protein and this increased protein ingestion, altho slight, may have been sufficient to stimulate the rate of growth. Secondly, it is possible that the heifer had reached the age at which the normal rate of growth called for less protein than was present in the ration. In other words, the heifer was approaching the age when only a maintenance ration for a mature animal was necessary. Thus it is possible that she was using the slight excess of protein, which had not previously existed, to make up some of the growth which had been retarded. This is

in accord with the theory on which feeding standards are based; namely, that, as the animal approaches maturity, the rate of growth decreases and the protein requirement per unit of live weight becomes less.

On January 21, 1915, the ration of No. 94 was changed to alfalfa hay, timothy hay, and starch and sugar. The chief source of the protein was then alfalfa hay instead of corn as previously. The mixture of corn starch and sugar supplied the necessary amount of energy value. After three or four days, the heifer consumed this ration with apparent relish. It was intended to keep the protein at the same level but the lack of an analysis of the hay previous to the feeding unfortunately brought about an increase during Periods 20 and 21, as previously mentioned.

The purpose of the change in ration was; first, to notice the effect of the mere change of feed; second, to note the effect of supplying minerals in organic form; and third, to change the source of protein, eliminating the incomplete protein, zein.

No marked increase in weight or height can be attributed to the change of feed. However,

a considerable improvement in the general appearance of the animal was evident. Her coat assumed a smoother appearance. She showed better spirits and was more active. From lack of evidence, we cannot consider the improved condition of the heifer, following the change of ration, as due to any one or to all the factors included in the change.

As regarding the amount of protein in the ration of No. 94 during Periods 18 to 22, we do not conclude that it was entirely sufficient. However, the evidence favors the conclusion that the amount much more nearly met the requirements of the animal than it had previously.

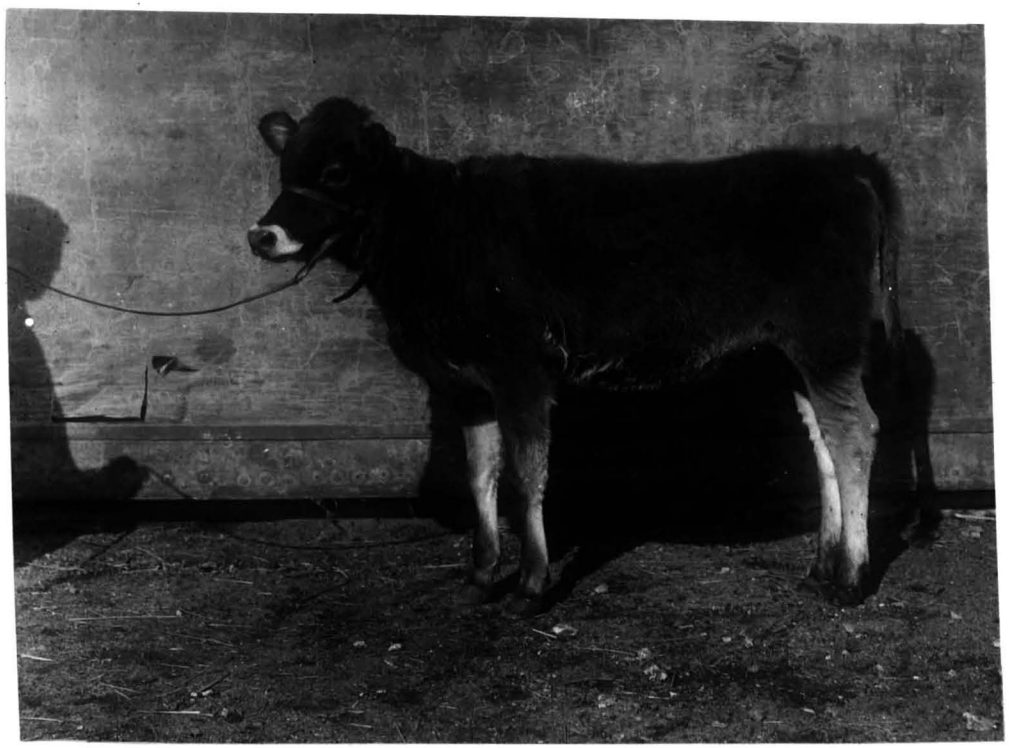


Plate I

No. 91 August 1913

Plate II

No. 94 August 1913

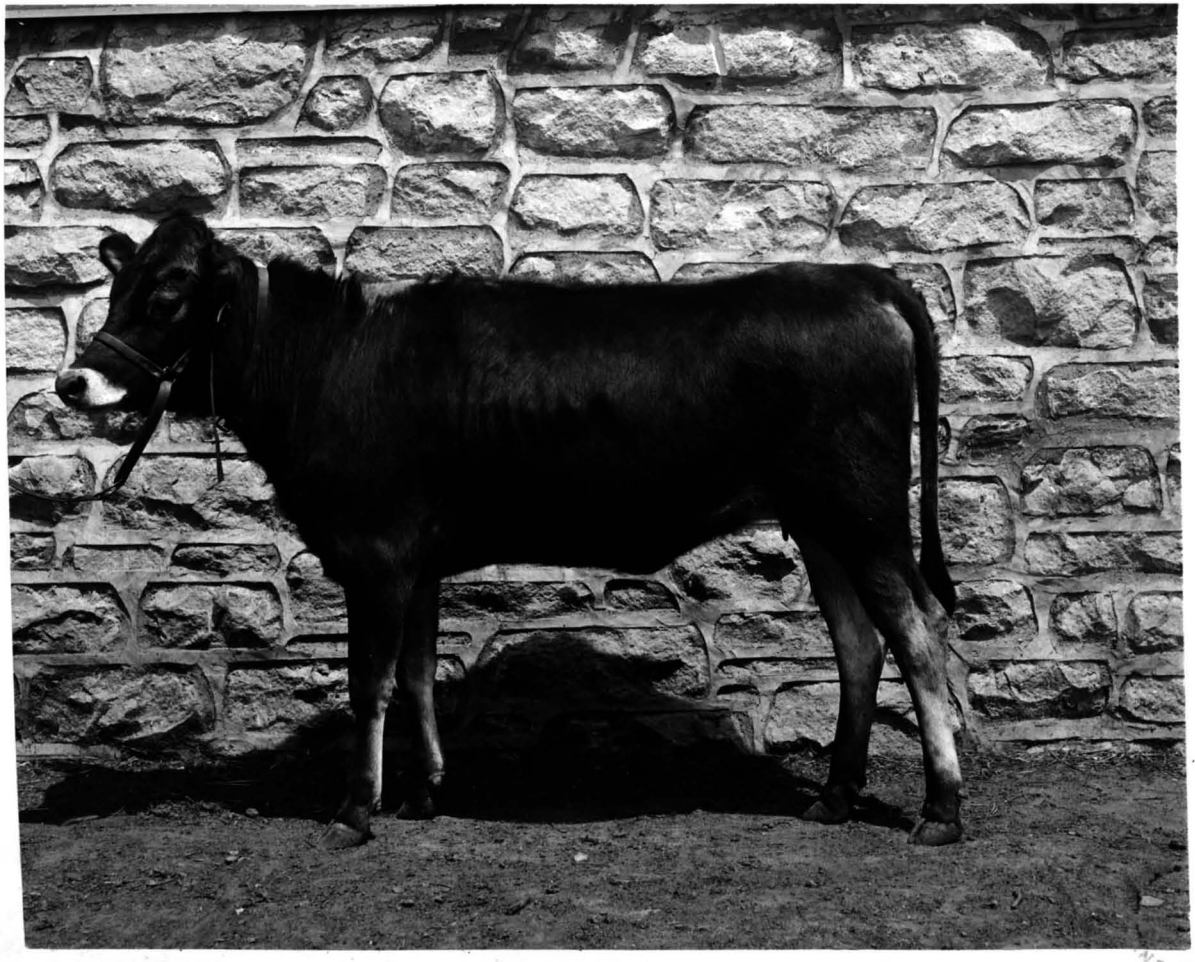


Plate III

No. 91 June 1, 1914

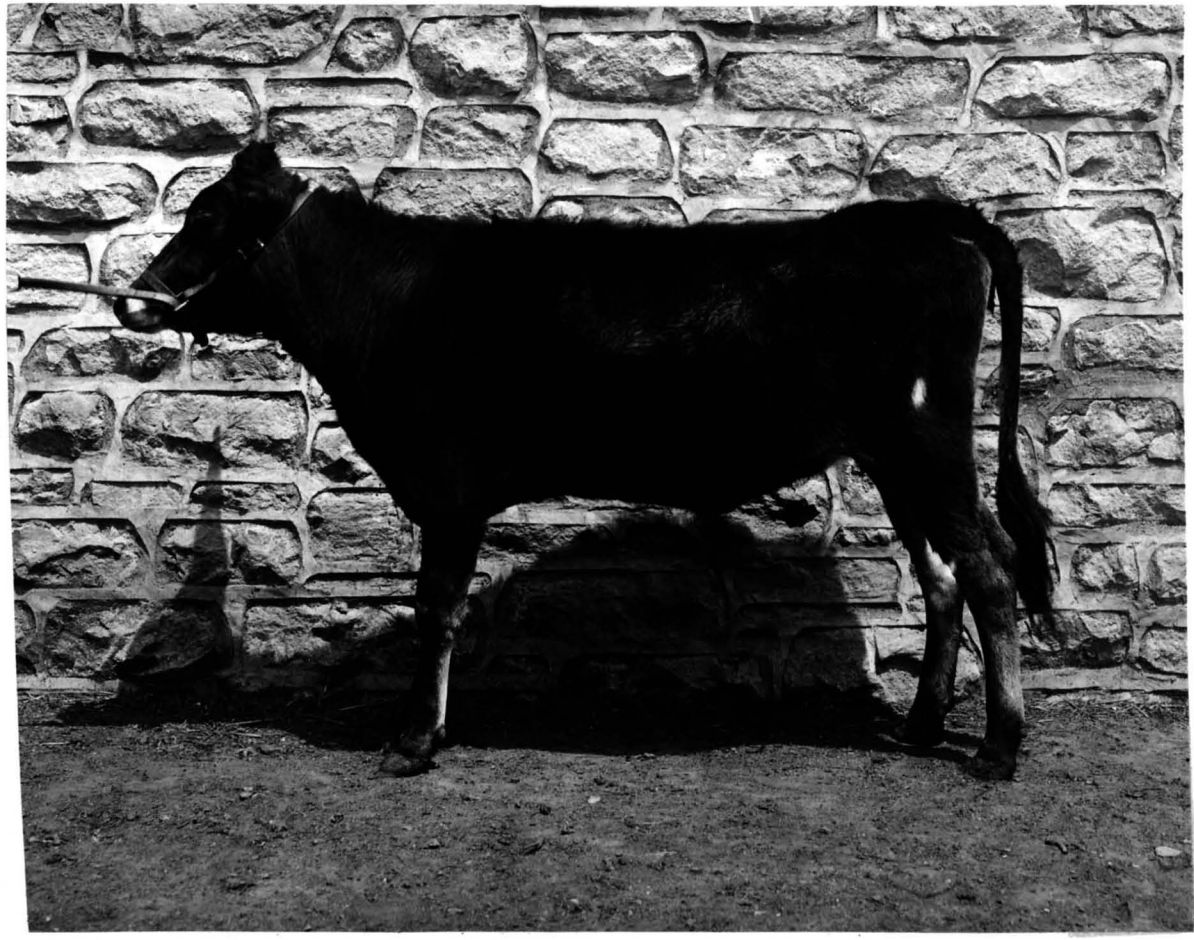


Plate IV

No. 94 June 1, 1914.

Plate V

No. 91 October 1, 1914.

Plate VI

No. 94 October 1, 1914.

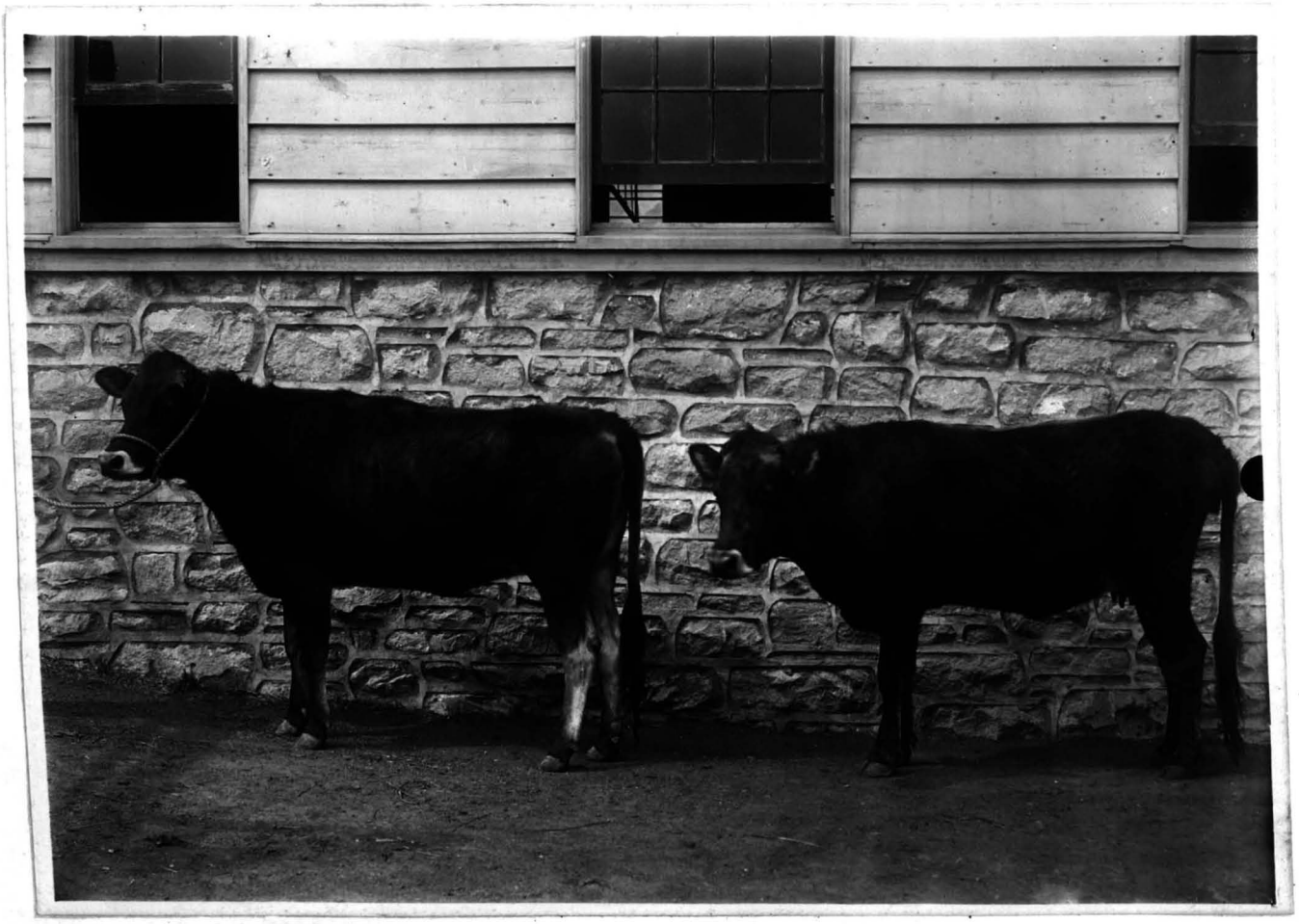


Plate VII

No. 91 No. 94

April 19, 1915.

Discussion of No. 250 and No. 103.

Object of Using More Animals in the Experiment -- In the previous discussion it has been shown that conditions, in the feeding of No. 94, were not so controlled as to entirely eliminate, as possible limiting factors, the mineral content of the ration and the quality of the protein. The purpose of continuing the experiment with more animals was to entirely eliminate, if possible, the above factors. Also it was desired to secure data on a number of animals on different planes of protein ingestion with the amount of protein as the only limiting factor.

Condition at Beginning of Experiment -- In December, 1914, the Holstein heifer, No. 250, and the Jersey heifer, No. 103, were placed in this experiment. The experimental records on No. 250 date from December 22, 1914, and on No. 103 from January 1, 1915. No. 250 was born May 27, 1914, and was 6 months and 25 days old at the beginning of the experiment. No. 103 was born June 23, 1914, and was 6 months and 8 days old at the beginning of the experiment. Both heifers were in good con-

dition but were somewhat under normal weight. No. 250, at six and one-half months, was about 30 pounds below normal and No. 103 was 20 pounds below normal at six months. Plates VIII and IX illustrate the condition of the heifers at the beginning of the experiment.

Plan of Feeding and Rations Fed -- It was planned to feed No. 250 the same amount of protein as was fed No. 94, regulating the amount by the weight of the animal rather than by age. The heifer was fed timothy hay to furnish roughage, skim milk powder as the chief source of protein, and a mixture of starch and sugar to supply a sufficient amount of energy. The casein and albumin of skim milk powder are both complete proteins and have been proven entirely efficient for maintenance and growth. $CaCO_3$ and bone meal were fed to supply calcium and phosphorus. Beginning in Period 4, potassium and magnesium were supplied in the form of citrates. It will be seen that the quality of the protein was eliminated as a factor. The mineral content of the ration was regulated by the amount of minerals in the ration fed No. 91, and from our knowledge of

the subject is believed to be sufficient. Under such conditions of feeding, we are of the opinion that all factors have been eliminated with the exception of the amount of protein. The object of feeding this heifer the same amount of protein as was fed No. 94 is to secure data from which it will be possible to determine whether the mineral content of the ration and the quality of the protein entered in as factors in retarding the development of No. 94, or whether the amount of protein was the only limiting factor.

It was planned to feed No. 103 a medium protein ration. The amount was set as halfway between the amounts received by No. 94 and No. 91 at the same weights. Such a plan, if followed strictly, would bring about undesirable fluctuations. Therefore it is intended to keep the curve of protein ingestion approximately a straight line, increasing the amount somewhat with the age of the heifer. The feeds used are the same as fed No. 250.

The work of the writer has been confined chiefly to the planning and conducting of the experiment with these two heifers, altho it has in-

cluded the general care and management of No. 91 and No. 94 since November, 1914. The period of feeding of No. 250 and No. 103 has not been long enough, at the present time, to supply data showing any definite results. The value of the work lies chiefly in the determination of methods of handling the problem in order to eliminate the factors involved, other than the amount of protein in the ration.

Experimental Data.

Table 8 gives the average daily consumption of the different feeds, by 30 day periods, for No. 250 and No. 103.

Table 9 gives the nitrogen content of the different lots of skim milk powder. The analysis of the timothy hay is given in Table 3.

Table 10 gives the average, by 30 day periods, of the nutrients received daily by the two heifers. The total protein of the skim milk powder was calculated from the total nitrogen by use of the factor 6.38. 95 was taken as the digestion coefficient for the protein of skim milk powder. This figure is the coefficient for the protein of skim milk, as given by Henry[1]. The calorie value of the skim milk powder was determined from the calorie value[2] of the pure nutrients, fat, protein, and sugar, contained therein.

Table 11 gives the weights and measurements of the two heifers by 30 day periods.

Table 12 gives the average daily gain in weight by periods and the digestible protein and energy used per pound of gain.

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1. Henry's Feeds and Feeding, 1912 Edition.
2. Bul. 71, Penn. Exp. Sta.

TABLE 8.

FEED CONSUMED DAILY BY 30 DAY PERIODS.

No. 250 - Low Protein.

Period	Timothy Lbs.	*Starch and Sugar Lbs.	Skim Milk Powder Lbs.	Bone Meal Gms.	$CaCO_3$ Gms.	Potassium Citrate Gms.	Magnesium Citrate Gms.
1	3.60	3.44	1.036	25.0	8.3		
2	3.45	3.50	1.218	38.3	10.0		
3	3.72	3.50	1.249	40.0	10.0		
4	3.60	3.50	1.249	65.0	5.0	15.0	30.0

No. 103 - Medium Protein

1	3.09	2.49	1.292	20.0	10.0		
2	1.70	2.82	1.523	36.6	10.0		
3	2.78	2.90	2.104	40.0	10.0		
4	3.00	3.00	2.446	40.0	10.0	10.0	27.5

TABLE 9.

NITROGEN CONTENT

OF SKIM MILK POWDER.

Lot No.	Per Cent Nitrogen	Periods Fed
1	5.437	Period 1
2	5.119	Period 2
3	5.445	Periods 3-4

TABLE 10.

NUTRIENTS RECEIVED DAILY.

BY 30 DAY PERIODS.

No. 250 - Low Protein.

Period	Age - Days Beginning of Period	Weight Average for Period	Digestible Protein Pounds	Energy Value Therms
1	209	360	.409	5.501
2	239	379	.433	5.652
3	269	390	.486	5.766
4	299	410	.490	5.726

No. 103 - Medium Protein.

Period	Age - Days Beginning of Period	Weight Average for Period	Digestible Protein Pounds	Energy Value Therms
1*	191	275	.484	4.562
2	211	284	.511	4.609
3	241	310	.752	5.499
4	271	344	.868	5.938

*Period 1 - 20 Days.

TABLE II.

WEIGHTS AND MEASUREMENTS BY 30 DAY PERIODS.

No. 250 - Low Protein.

Period	Weight Pounds	Height at Withers Centimeters	Width of Hips Centimeters	Heart Girth Centimeters
1	360	102.3	29.5	120
2	379	105.0	31.0	122
3	390	107.8	32.0	125
4	410	108.4	32.5	127

No. 103 - Medium Protein

1	275	95.5	27.5	115
2	284	98.3	28.5	116
3	310	100.9	30.5	121
4	344	103.4	33.0	130

TABLE 12.

AVERAGE DAILY GAIN BY 30 DAY PERIODS

and

DIGESTIBLE PROTEIN AND ENERGY USED PER POUND GAIN.

No. 250.

Period	Daily Gain Pounds	Pounds Protein per Pound Gain	Energy Value Therms Per Pound Gain
1	1.17	.35	4.70
2	.33	1.31	17.13
3	.53	.92	10.88
4	.67	.73	8.55

No. 103.

1	1.10	.44	4.15
2	.27	1.89	17.07
3	1.43	.53	3.85
4	1.00	.87	5.94

*20 Days.

Plate VIII

No. 250 December 1914

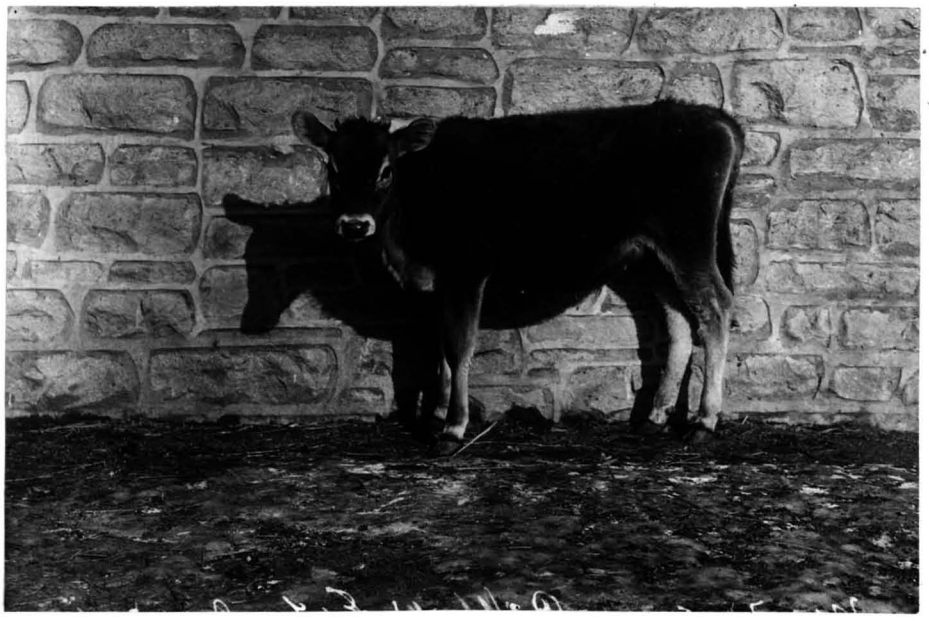

Plate IX

No. 103 December 1914

Plate X

No. 250 April 19, 1915.

Plate XI

No. 103 April 19, 1915.

Discussion of Data.

At this writing, records have been secured on No. 250 and No. 103 for only four months. From such limited data it is impossible to draw any definite conclusions. The results obtained thus far can be considered only as indications of the final effects which the feeding may produce.

It was stated that No. 250 was 30 pounds below normal weight at the beginning of the experiment. The average of the last three-day weights taken show the animal as 76 pounds below normal. Thus, normally, she should have gained in weight 46 pounds more during the four months. At the beginning of the experiment, the height at withers of the heifer was 3.6 centimeters below normal. At the end of four months she was 3 centimeters below normal. These facts would indicate that the rate of increase in weight of the heifer had been retarded but that the increase in height had been normal. This check of increase in weight would in turn be a possible indication that the amount of protein in the ration was insufficient.

No. 103 was 20 pounds below normal weight before she was placed in the experiment. At the

last weighing, she was 35 pounds below normal. This check of increase in weight is so slight that it means nothing. Growth in height of the heifer has been entirely normal. The results to date seem to indicate that the heifer has developed normally on the medium amount of protein which she received.

Plates X and XI are photographs of the heifers taken at the end of Period 4. No. 103 has at all times appeared in normal condition. The same has been true of No. 250 with the exception that she has appeared somewhat thin in flesh. Both heifers have appeared bright and active at all times.

As a matter of interest, the reasons for feeding, the methods of feeding, and the palatability, of the somewhat unusual ration fed No. 250 and No. 103 will be discussed briefly.

As previously stated, the reason for feeding the skim milk powder was to eliminate the quality of the protein as a factor. Protein from this source is known to be complete and has been proven to be entirely efficient for growth and maintenance. This appeared to be the only feed which was both

available and practical and at the same time fulfilled the requirements as a source of complete protein. Starch and sugar was fed to make up the required energy value of the ration. The value of this mixture lies in the fact that any amount of energy can be secured from this source without varying the protein content of the ration. Sugar was fed with the starch in order to make it more palatable.

With No. 250 in particular, it was desired to feed each day a definite amount of protein. This fact and the high protein content of the skim milk powder necessitated the weighing out of each feed, separately, in grams. This amount was mixed with the required amount of starch and sugar and given the heifers in the same manner as grain would be fed. The timothy hay was fed in the ordinary manner.

On the whole, the ration has proven very satisfactory. For a time, both heifers showed considerable aversion to the powder mixture. However, after two or three weeks, they consumed it readily and have refused only small amounts from

time to time. For the first two weeks, the ration caused the heifers to scour somewhat. Since then, however, the feces from both heifers has been entirely normal. This would indicate that the nutrients supplied were readily available to the animals.

Heifer No. 253

In the discussion of No. 94, it was stated that the ration of alfalfa hay, timothy hay, and starch and sugar, which was fed that heifer, was consumed very readily. This appeared to be another solution of the problem of securing a a palatable and efficient ration in which the amount of protein and energy value could be easily regulated. The amino-acid make-up of the protein of alfalfa hay is not known and in this respect alfalfa is not so desirable a source of protein as is skim milk powder. But alfalfa hay has an added advantage of supplying a large amount of minerals in organic form. By varying the relative amounts of alfalfa and timothy hay, the protein content of the ration can be made to meet any required amount. At the same time the proper amount of

roughage can be supplied. The starch and sugar mixture supplies sufficient energy without varying the protein content. It has been our practice to feed the starch and sugar mixed with cut hay.

On April 21, 1915, the Holstein heifer, No. 253, was placed in this experiment and will be fed a medium protein ration. The ration fed is alfalfa hay with starch and sugar. As it becomes necessary to increase the amount of roughage in the ration, timothy hay will be fed with the alfalfa hay. It is planned to keep this heifer on approximately the same plane of protein ingestion as No. 103. At six and one-half months she is weighing 380 pounds and is receiving daily .583 pounds of digestible protein and 5.58 therms of energy value. These nutrients are supplied by 4.4 pounds of alfalfa hay and 4 pounds of the starch and sugar mixture.

SUMMARY AND CONCLUSIONS.

The investigation herein reported is a feeding experiment to determine the effect of the amount of protein in the ration upon the growth of dairy heifers. In an experiment of this kind it is essential to eliminate as factors the energy value of the ration, the mineral content of the ration, and the quality of the protein.

The Jersey heifer, No. 91, was placed in the experiment as a check animal and was fed a ration believed to be sufficient in every way. The ration fed at first was alfalfa hay, corn, bran, and cottonseed meal. The bran and cottonseed meal were later omitted. As anticipated, the data secured indicates that the development of No. 91 was entirely normal and thus there were no limiting factors in the ration.

The Jersey heifer, No. 94, was placed on a low protein ration. She received from one-third to one-half the amount of protein fed No. 91. The energy value of the rations of No. 94 and No. 91 was practically equal. The ration fed No. 94 until she was two years of age was corn and timothy hay. On this low protein ration, the heifer in-

creased in weight but 54 percent and in height but 73 percent of the normal. However, the failure to develop normally cannot be attributed entirely to the low amount of protein in the ration.

Since No. 94 received as much energy value as did No. 91, it is concluded that the energy value of the ration of No. 94 was not a factor in retarding the growth of the heifer.

For the reasons given below, the possibility is admitted that the mineral content of the ration of No. 94 may have been a limiting factor.

The mineral content of the ration of No. 94 was not equal, for a large part of the time, to the mineral content of the ration of No. 91.

A large part of the calcium and phosphorus supplied No. 94 was in inorganic form.

We have no definite knowledge of the actual mineral requirements of the growing heifer or of the availability of inorganic calcium and phosphorus.

During the time when the ration of No. 94 was corn and timothy hay, the incomplete protein,

zein, known to be inefficient for growth or maintenance, comprised approximately 40 percent of the total protein in the ration. Thus the quality of the protein in the ration of No. 94 was a possible limiting factor.

The amount of protein in the ration of No. 91 fluctuated widely but on the average approximated the amount called for by the Wolff-Lehmann Standard. It is concluded that this amount of protein was entirely sufficient.

Until 22 months of age, No. 94 received less than one-half pound of digestible protein daily. It is concluded that this low amount of protein was the chief factor in retarding the growth of the heifer.

After No. 94 was 23 months of age, her average daily ingestion of protein was about .6 of a pound. During this time, her rate of increase in height and weight was slightly greater than the normal rate for that age. This fact would indicate that such an amount of protein is sufficient for growing heifers after two years of age.

For the purpose of securing data on animals fed a ration in which all factors, other than the amount of protein, were eliminated, three more heifers have been placed in this experiment.

The Holstein heifer, No. 250, was fed the same amount of protein as was fed No. 94. The ration fed was timothy hay, skim milk powder and starch and sugar. The energy value was made sufficient. Skim milk powder as the source of protein eliminates the quality of protein as a factor. Calcium, phosphorus, magnesium, and potassium are supplied, making the mineral content of the ration equal to that of the ration fed No. 91. The rate of increase in weight of the heifer, during four months, has been retarded. This is an indication that the amount of protein in the ration is too low and is a further indication that the low amount of protein in the ration of No. 94 was the chief factor in retarding the growth of that heifer.

The Jersey heifer, No. 103, was placed on a medium protein ration. She is fed a ration similar to that fed No. 250. During four months,

the development of this heifer has been entirely normal. This is an indication that the amount of protein fed No. 91 was unnecessarily high.

The Holstein heifer, No. 253, has been placed on a medium protein ration. Alfalfa hay is fed as a source of protein and of minerals, and a mixture of starch and sugar is fed to make up the required amount of energy value. Data has been secured on this animal for less than a month at the present time.

The data secured thus far warrants the following general conclusions as to the amount of protein for growing heifers:-

An amount of digestible protein equal to the requirements of the Wolff-Lehmann Standard is entirely sufficient for the normal development of dairy heifers. Moreover, our data indicates that such an amount is unnecessarily high. Less than one-half pound of digestible protein daily, until the animal is two years old, is not sufficient for normal development.

ACKNOWLEDGMENT

The writer wishes to express his appreciation to C. H. Eckles, Professor of Dairy Husbandry, University of Missouri, for his helpful suggestions in the preparation of this paper.

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