THESIS

THE EFFECT OF A RATION LOW IN CALCIUM ON THE GROWTH AND HEALTH OF DAIRY HEIFERS

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by

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INTRODUCTION

Instinct and appetite have long been the guiding factors in the nutrition of dairy cattle, but due to the development of the dairy cow to her present high state of efficiency these factors can no longer guide us. Dairy cattle are now fed a ration high in concentrates, which are very low in calcium, while the cow in her early state pastured and lived primarily on roughage, the chief source of this element.

Calcium and phosphorus are the chief constituents of the animal body; they are,also, quite as important as plant foods and in the latter relation demand very prominent consideration as elements of soil fertility.

Many of our soils are benefited by liming and most of them are improved by applications of phosphate fertilizers. As the stores of these elements in the soil become depleted they come to be limiting factors in the growth of plants. Not only is the yield decreased but the calcium and the phosphorus content of the crop grown on soils deficient in these elements is decreased by the poverty of the soil. Further, when these crops are used as food for

animals, their low calcium and phosphorus contents become, in certain cases, limiting factors not only in production of bone, muscle, eggs and milk, but also in the maintenance of normal conditions in other fundamental physiological processes.

Eckles, while at the Missouri Experiment Station, carried on an experiment with two Jersey heifers, one on a low calcium ration, the other on a high calcium ration. The heifer on the low calcium ration gained in weight and grew just as fast as the one on the high calcium ration. However, at the end of thirteen months on the experiment the heifer on the low calcium ration showed symptoms of an abnormal condition. The first indication was a stiffness in the joints and abnormal gait in walking, which gradually became worse. This ration was derived almost entirely from the corn plant and it has been definitely shown that the corn plant does not form a complete ration even though it is low in calcium.

These results do not bring out the exact effect of a ration low in calcium on a dairy heifer because Eckles had more than one factor entering into the results. This lead to the selection of the problem, namely, the effect of a ration low in calcium, but otherwise adequate, on the growth and health of dairy heifers.

GENERAL DISCUSSION AND REVIEW OF LITERATURE

Growth

Growth is probably the most important factor that may be influenced by a ration low in calcium. The major purpose of this problem was to determine the effect of a ration low in calcium on the growth of dairy heifers, because, after all, what does it matter if an element is lacking in the ration if its deficiency has no bearing on the growth.

We know that people grow, animals grow, but why do we grow? What causes us to grow? What is the nature of the substance, if it is a substance, that causes us to grow? We know that people and animals grow but we very seldom stop to think in terms of why, the nature and cause of it. How is growth defined? Mendel (1) defines it as a resultant of an inherent growth impulse - an internal factor and a suitable environment. Armsby (2) defines growth as an increase of the structural elements of the body - chiefly by cell multiplication resulting in a gain in size and weight. Huxley (3) says growth is an increase in volume or size. Eckles (4) says growth is usually understood as an indicatice of that series of physiological changes by which an individual of any species develops from the fertilized egg to maturity. The fertilization sets free the growing impulse.

Growth in the language of a chemist is exemplified in the contention that growth appears to be, "the expression of autocatalytic chemical reaction", and particular cycles of growth of an organism are accordingly shown to obey a precise mathematical formula.

We have defined growth to the best of our knowledge. Now we will try to see what is the cause of growth.

There are a number of theories of growth but none of them seem to fit the case. It has been alleged that growth is stopped because an animal can digest only a limited quantity of food, and that the adult (stage) size is that stage of equilibrium between the amount of food digested and the amount used. Experiments however condemn this theory. Aron (5) says the force which induces growth, resides in the skeleton (growth tendency). It is more noticeable in the skeleton than any other part of the body because the skeleton of a fasting animal grows at the expense of the rest of the body.

Growth may be divided into two main factors - internal and external. The internal factors are inheritance, internal secretions and hormones. The external factors are those controlled to some extent by man, as nutrition, heat, light, age, period of gestation, period of lactation

and early breeding. Going back to the internal factors we have first inheritance. This limits the capacity for growth. This can not be controlled after fertilization of the egg. It sets the limit of growth. The internal secretions produced by the thyroid gland, pineal gland, etc. all influence growth; if removed stunted growth is the result.

Hormones also influence growth. Killicott (6) thinks that the growth of each gland or tissue depends on a specific hormone - a growth regulator - by inhibition of acceleration.

The external factors can only give free scope to the inherent tendency to grow. In nutrition in order to give the growth impulse free sway the animal must have carbohydrates, adequate protein, mineral salts, vitamines and water. Aron found that an animal could grow for some time without calcium and phosphorus.

Growth is a very important problem because we are always endeavoring to get maximum growth, and in order to do this we must understand the factors entering into it. The production of plants and animals alike are based upon growth.

It may be well to take up the nature of growth, that is, follow its course from beginning to end. Minot (7) says the decline in growth power is rapid at first and gradually slows up until growth stops entirely. The size of the germ of the mammal at the start is from .6 to .3 milligrams. In the human species, the germ at the end of the first month has increased one million percent. According to Jackson (8) the increase in size of the human fetus at end of the first month is ten thousand times, second month, seven hundred times, third month, eleven times, fourth month, forty-five hundreths times. This shows very clearly the rapid decline in rate of growth.

According to Minot (7) rate of growth in rabbits in fetus from nine to fifteen days increase in weight seven hundred per cent. Fifteen to twenty days increase in weight two hundred and twelve per cent. He estimates that ninety-eight per cent of the power of growth has been lost at birth or hatching in the case of rabbits and chicks, which is equally true of man. In the case of guinea pigs a lessening of growth is shown for several days after birth, due to physiological shock suffered when born. They recover in three or four days and have capacity to grow

five per cent per day. At seventeen days only able to gain four per cent and at the end of twenty-four days less than two per cent. At forty-five days a little over one per cent. The average weight of a colt at birth is one hundred and twelve pounds, the average daily increase the first three months is two and two tenths pounds per day. From three to six months one and three tenths per day. From six months to three years seven tenths pound per day. Horses grow until six years of age. A calf at birth weighs seventy-seven pounds, average daily gain first two years one and five tenths pounds.

Frieddenthal (9) has developed the following figures to show the per cent of increase of the foetus in human beings up to birth.

Age in Days	Per cent Increase Per Day
8	90,000
17	307
20	16
26	6
35	7.5
100	3.0
196	1.1
280	0.5

Minot (7) made the following analyses of the milk of different species to show the relationship to the rate of growth.

Species	Days needed to double weight	Parts per 100 parts mother's milk			
		Proteid	Ash	Ca	Ph acid
Man	180	1.6	.2	.0328	.0475
Horse	60	2.0	.4	.124	.131
Cow	47	3.5	.7	.16	.197
Goat	19	4.3	.8	.21	.322
Pig	18	5.9	-	-	-
Sheep	10	6.5	.9	.272	.412
Cat	9.5	7.0	1.0	-	-
Dog	8	7.3	1.3	.453	.493
Rabbit	7	10.4	2.4	.8914	.9967

This is an example of correlation and not causation because if we feed cow's milk or sheep's milk to an infant it grows at the human rate and not at the rate of the calf or lamb.

According to Minot (7) protoplasm is the physical basis of life but an undue increase in protoplasm in proportion to the growth of nucleus seems to cause an alteration in the condition of the living cell; which causes old age. Rapidity of growth depends on the relation of protoplasm to nucleus. The larger the nucleus up to a certain point the more rapid is growth. In the cell of the salamander when muscle development begins until adult life there is a seven fold increase of protoplasm over nuclei. Fertilization of the ovum is followed by an enormous synthesis of nuclear matter, and each nucleus is the same size as the parent nucleus. Loeb concludes from this that the nucleus itself or one of its constituents acts as a catalizer in the synthesis of nucleus in the fertilized ovum.

According to Lee (10) growth is brought about by three main processes. (1) Cell multiplication, which is the important factor from time of fertilization until birth, because after birth very little cell multiplication takes place. (2) Cell enlargement, which is the important factor after birth until maturity. (3) Disposition of intercellular matter, which also is one of the factors considered after birth. The first two are the most important.

There are three main types of growth. Different tissues have unlike power of growth in the sense of cell multiplication, as

(1) Testes multiply their cells throughout life but their function is delayed at first followed by accelerated growth.

(2) Muscles and nervous system show growth or development only in the embryonic stage.

(3) Brain shows very rapid growth followed by very slow growth while others such as heart, kidneys, etc., show even growth.

Rubner (11) formulated two general laws of growth.

(1) The law of constant energy consumption. To form one killigram of animal weight requires 4808 calories of food while for man six times as much is needed.

(2) Law of constant growth quotient. In mammals except man the same fractional part of the entire food energy is utilised for growth. Growth quotient is 34 per cent in mammals, that is out of every 1000 calories used for food 340 are used for growth. In man the growth quotient is 5 per cent.

According to Bover (12) cell division is regulated by the proportion of chromatin material to cytoplasm. Growth stops when the ratio of chromatin to cytoplasm reaches a certain point.

Relation of Minerals to Growth. The old assumption was that domestic animals secured sufficient mineral matter from any ordinary rations. This is true only to a certain extent depending entirely on the kind of roughage included in the ration. We are endeavoring always to secure maximum growth with dairy heifers. This makes it very important that we consider all the things necessary for the free exercise of the growth impulse.

At present as a result of extensive investigations of Forbes, Hart and McCollum, and others, the tendency is to raise the question of possible deficiencies in mineral matter in the rations of all farm animals. The work presented in this thesis was conducted for the purpose of observing the effects of a ration deficient in lime on the growth and health of the dairy heifer.

The functions of mineral elements in animals nutrition have not kept pace with the advancing knowledge along other lines of nutrition.

There are a number of reasons for this: first, animals need comparatively little of mineral nutrients in their food; second, the animal body serves as a vast supply of these nutrients in times of need, so that a ration deficient in mineral nutrients is not noticed for considerable time or may never be noticed as time goes on and the animals are changed from one kind of feed to another.

Forbes (13) of the Ohio Experiment Station and Hart (14) and McCollum of the Wisconsin Station have found that milch cows invariably show a negative calcium balance when producing heavily. But on the other hand Meigs (15) of the U. S. Department of Agriculture found that milch cows store large amounts of these materials during a dry period or

period of rest if properly fed. Then again redigestion and reassimilation of mineral matter from certain waste products which have been excreted into the intestine may help to stave off the critical point. These facts all go together to make up the question of the possible deficiency of minerals that may not be noticed. It may be possible to obtain more growth and possibly larger and more efficient production with dairy cows with the proper use of minerals.

It is estimated that about eighty-five per cent of the mineral matter of bone or at least three-fourths of the entire ash of the body consists of calcium phosphate. Probably over ninety-nine per cent of the calcium in the body belongs to the bones, the remainder occurring as an essential constituent of the soft tissues or body fluids. According to Lusk (16) about seventy-one per cent of the magnesium in the body is in the bones. The muscles contain considerably more magnesium than calcium, and the blood contains more calcium than magnesium. That calcium salts are necessary to the coagulation of the blood has long been known and frequently cited as an example of the great importance of calcium salts to animal economy. Equally striking is the function of these salts in regulating the action of the heart muscle.

Rickets

According to the results of many investigators, rickets has been found to be due to a deficiency of calcium in the ration, which suggested the possibility that dairy heifers fed a diet extremely low in calcium may develop this disease.

Rickets has been known to writers for years but was confused with skeletal deformities. Glisson (17) in 1650 gave the first accurate definition and description of the disease. Rickets is defined by Park (18) as a disturbance in the metabolism of the growing organisms of such a nature that the salt equilibrium, in particular as regards the calcium and phosphorus, in the circulating fluids is disturbed, and lime salts no longer deposit in the bones. Lime salts may not deposit because the ionized calcium in the blood is low, or because the ionixed phosphate is low or because both are low.

Rickets occurs chiefly in Europe and North America. It is a disease found in cities, and is most prevalent in those nations whose wealth and industrial development have brought about most fully the substitution of artificial conditions of living in place of the simple conditions which

nature intended. The disease has never been found in people who tend to live under natural conditions. It occurs rarely in the tropics and is very rare in the artic regions.

Jost and Kook (19) state that rickets is a common disease among pigs, puppies, lambs, and kids, but less common among colts, calves and rabbits. It manifests itself with comparative frequency among carnavorous animals and also among monkeys in captivity. The striking facts concerning the occurrence of rickets among animals are as follows: The disease appears only among those animals which man has been able to make captives and upon which he has been able to impose artifical conditions of environment and diet. The disease never develops among animals living apart from man and probably can not develop in animals or in man in a wild state. Hansemann (20) points out that the cat, in contrast with the dog, never develops rickets. He gives as his reason the fact that the cat, though tamed can never be made to relinquish the habits natural to its species. Rickets develop frequently in the monkey when he is in the zoological garden but never when he is at liberty.

According to Park (18) rickets is so common in the large cities of America and Europe that few children among the poorer classes are untouched by it.

There are several theories concerning the cause of rickets. Gilsson believed that rickets was the result of over eating. Heitzmann proposed that the disease was caused by an acidosis which brought about a decalcification of the bones. The theory that rickets is due to defective diets is gaining ground. It is maintained that rickets is due to lack of calcium salts in the diet, or a lack of proper utilization of calcium. There is also a theory that lack of exercise or sunlight causes rickets.

The Relation of Exercise and Sunlight to Rickets. The idea that the primary cause of rickets lies in the inability of the animal to gratify a natural impulse for exercise is difficult to accept because some years ago Howland and Park (21) and later Baldwin confined puppies in small cages for two or three months but could not obtain rickets in that way. Mellanby (22) also showed clearly that confined puppies will not develop rickets provided the diet is properly constituted.

Hess and Unger (23) were able to protect rats from rickets by sunlight, on a diet deficient in phosphate.

The seasonal variation shows that it is largely climatic and is due almost entirely to a lack of sunlight. This is shown by the pathological studies of Schmorl (24).

These studies showed that rickets may begin at any time but the highest percentage of early manifestations of the disease is between November and May. The percentage of cases with signs of healing increased as the summer progressed and reached its highest point in the autumn only to fall again as the winter months came.

There is no doubt that rickets is not only hygenic but also dietetic disorder. This is clearly shown because rats fed an ideal diet do not develop rickets when kept in the dark. But on the other hand a poor diet and lack of sunlight is nearly sure to develop rickets. The amount of sunlight required to prevent or cure rickets depends entirely on the diet, rate of growth and the pigment of the skin. More sunlight is required for protection when the diet is poor, also when the rate of growth is rapid.

In June 1919 Huldschinsky (25) reported that the ultra violet ray exerted a curative action in rickets. He treated four children who had advanced rickets with the mercury vapor quartz lamp and found that at the end of four weeks it was possible to demonstrate with the X ray deposits of limestone at ends of the long bones of the extremities. After two months the healing seemed almost complete.

The discovery by Huldschinsky of the curative action of light in human rickets has been corroborated by Putzig, Korger, Hess and Unger, and by Huldschinsky himself in numerous additional experiments. Powers, Park, and Shipley, cooperating with McCollum and Simmonds (26) report that rats fed a diet capable of producing rickets at ordinary room light were prevented from showing any signs of the disease by exposure to sunlight.

It seems from the review of literature that sunlight has the same effect in the prevention of rickets as does vitamine "D". Of course if the calcium intake is too low vitamine "D" can only aid in the retention of the calcium taken in and will not prevent rickets alone. However, it has not been proved whether a liberal supply of vitamine "D" with a very low calcium supply will prevent the development of rickets.

Relationship of Cod Liver Oil to Rickets. Cod liver oil has been used from time immemorial as a folk-remedy on the coasts of England, Holland and France. The direct proof of its curative action, however, was first obtained by McCollum and Simmonds (27). These investigators discovered that cod liver oil caused deposition of lime salts to form in the cartilage of the rachitic rat. Howland and Park (28) proved by means of the X Ray that the administration of cod liver oil to rachitic children was followed by the deposition of lime salt in the cartilage and bone after a period of from 15 to 21 days.

Relation of Vitámine "D" to Calcium Retention.

McCollum has just recently suggested that we call this factor in cod liver oil, vitamine "D". Holt, Courtney and Fales (29) kept a child on a diet containing vegetable fats, which was practically free from fat soluble "A". The child stopped growing, but remained in good general condition, which indicates that the anti-rachitic factor may be separated from fat soluble "A".

In January 1922 McCollum, Simmond (26) and Shipley and Park (30) made the following statements. "The results of this series of experiments was so consistent and decisive that we can deduce no other conclusion than that cod liver oil contains an abundance of some substance which is present in butterfat in but very slight amounts, and which exerts a direct influence on the bone development, and enables animals to develop with an inadequate supply of lime much better than they could otherwise do. This substance is apparently distinct from Fat Soluble "A" which is essential for growth and which is associated definitely with the prevention of ophthalmia."

In June 1922 McCollum, Simmonds, Becker and Shipley (31) succeeded in obtaining striking evidence of the existence of a substance in cod liver oil distinct from butter fat which causes the deposition of lime salts in the bones of rats rendered rachitic by the diet. In this experiment fat soluble "A" in cod liver oil was destroyed first. This was proved by the fact that when it was fed to rats it failed to cure xeropthalmia but when fed to rats rendered rachitic by means of the diet it caused lime salts to be deposited in the bones. It was very difficult to escape drawing the conclusion that the factor in cod liver oil causing the deposition of lime salts is distinct from fat soluble "a". McCollum concluded that there was a fourth vitamine and suggested that we call it Vitamine "D".

Hart, Steenboch and Hobart (32) obtained a negative calcium balance when cabbage was fed to goats and orange juice also failed to alter calcium metabolism which led them to conclude that the anti-scorbatic factor was not instrumental in producing calcium assimilation. But when fresh green oats were compared with dry oat straw the green oat straw increased the amount of calcium assimilated. Like results were obtained with oat hay, dried out of direct sunlight but in a fairly well lighted attic.

They concluded that the same factor effecting calcium assimilation was in green oats and grasses as is found in cod liver soil. It is evident that some green plants contain the anti-rachitic factor but it is not a constituent of all green plants.

The whole thing can be summed up to the fact that there are three factors concerned in the utilization and assimilation of calcium and phosphorus in the ration. (1) an ample supply of calcium, (2) an ample supply of phosphorus, (3) the presence of vitamine "D" which aids in their assimilation. Without the latter there is only limited use made of the calcium and phosphorus in the ration.

Tetany

Tetany is closely connected with rickets in that both are due to a deficiency of calcium. Rickets is due to lack of calcium in the bones while in tetany the muscles and nerves suffer due to a deficiency of this element. This also suggested the possibility of tetany developing in heifers fed on a diet very low in calcium.

Low Calcium in Tissues the Cause of Tetany. That tetany is caused by a low calcium content of the tissues seems to be the most widely accepted theory. Sabbatani (33) first suggested that the decrease in content of calcium in the brain caused the irritability of the nervous tissues, since he had observed that when calcium chloride was applied to the cortical surface the irritability was immediately reduced and with antagonistic reagents such as sodium citrate the reverse was true. Following the above suggestion Quest found that the calcium content of the brains of patients dying from tetany was greatly diminished when compared to the normal brain of the same age.

McCollum and Voegtlin (34) were able to stop symptoms of tetany by giving 100 c.c. of 4.3 per cent of calcium lactate by the stomach pump. Their results show that calcium administration in tetany is very similar no matter whether given intravenously, subcucaneously or by stomach tube.

There are few writers that have carried on experiments and state that tetany is not due to a deficiency of calcium but is due to some other factor as a poison in the blood but the balance of evidence and most accepted theory is that it is due to lack of calcium in the blood and tissues.

Ion Antagonism as the Cause of Tetany. There has been advanced a theory that tetany is due to an irritant effect of certain ions on the body tissue. Loeb (35) experimenting with frogs found that certain ions coming in contact with the nerves, a tetanus condition resulted while other ions if present tend to counteract the irritative effect. Tetany seems to be a condition in which the normal balance between calcium and magnesium on one side and potassium and sodium on the other is disturbed so that when the ratio of sodium and potassium to calcium and magnesium becomes large enough the potassium and sodium set up irritability and the injection of calcium will restore this normal condition.

The two theories seem to have the same cause. If the calcium in the tissues becomes low than the potassium and sodium ions set up irritability causing tetany; however, as long as the calcium in the tissues is at the proper level tetany does not result.

The Calcium Requirement

The body is made up of a number of different elements. According to Sherman (36), who takes his figures from various writers, the average elementary composition of the human body may be presumed to be approximately as follows:

Oxygen about	65. per cent
Carbon "	18. "
Hydrogen "	10. "
Nitrogen "	3. "
Calcium "	2. "
Phosphorus	1. "
Potassium"	.35 "
Sulphur "	.25 "
Sodium "	.15 "
Chlorine "	.15 "
Magnesium"	.05 "
Iron "	.004 "
Iodine	(Very
Fluorine	(minute
Silvion	(quantities

Also, traces of some other elements such as manganese and aluminum may perhaps be normal constituents of the body, and even arsenic has been discussed as a possible essential element.

All these substances in the body are continually undergoing disintegration and renewal. Therefore, it follows that there must be a constant metabolism or exchange of every element which enters into body structure. More or less

of each element must be metabolized and eliminated each day; and if equilibrium is to be maintained an equal amount must be supplied.

The simple proteins furnish only five of the fifteen chemical elements which are known to be essential to human nutrition, while carbohydrates and fats are composed of but three of these five. Ten of the fifteen essential elements, or seven of the twelve which are essential in amounts sufficiently large to be measurable by present methods, must therefore be furnished by some ingredients taken in other than simple proteins, carbohydrates and fats.

It can easily be seen that the calcium is the most important of the mineral salts or inorganic elements. The phosphorus is next in importance because they are very closely associated to a large extent in calcium phosphate.

The elements concerned in "mineral metabolism" may exist in the body and take part in its function in at least three different ways.

(1) As bone constituents, giving rigidity and relative permanence to the skeletal tissues. This is the place that most of the calcium is found.

(2) As essential elements of the organic compounds which are the chief solid constituents of the soft tissues such as muscles, blood cells, etc.

(3) As soluble salts held in solution in the fluids of the body, giving these fluids their characteristic influence upon the elasticity and irritability of muscle and nerve, supplying the material for the acidity or alkalinity of the digestive juices and other secretions, and yet maintaining the neutrality or slight alkalescence of the internal fluids as well as their osmotic pressure or solvent power.

The Effect of Withholding Calcium from the Ration. As has been pointed out a larger proportion of the body is composed of calcium than of any other inorganic element.

In studying the effects of insufficient calcium, Voit (37) kept a pigeon for a year on calcium-poor food without observing any effects attributable to the diet until the bird was killed and disected, when it appeared that, although the bones concerned in locomotion were still sound, there was a marked wasting of the calcium salts from other bones such as skull and sternum, which in places was perforated.

Hart, McCollum and Humphrey (38) fed an 1150 pound cow producing about 30 pounds of milk daily a liberal ration except that it lacked lime. It was found that there went into the milk daily about 20 grams of lime and into the solid excrement and urine, principally the former, about 30 grams, the latter loss being due to normal changes (metabolism) taking place in the body. In all about 50 grams of lime disappeared daily from the body of this cow, only one half of which could have been furnished by the lime in the food. During the trial which lasted 110 days this cow maintained a good flow of milk and continued to put the normal amount of lime into it. It was calculated that during the trial she gave off in milk and excrement 5.5 pounds more lime than she received in her food. It was estimated that her skeleton contained about 24.2 pounds of lime at the start and this being true this cow gave up in 110 days about 25 per cent of all the lime in her skeleton.

Thus an animal may continue to lose calcium from the bones going to the blood and tissues without any definite symptoms developing for considerable period and then the time is not definitely known.

The injurious effect of an insufficient lime intake is more noticeable in fast growing animals then with full grown animals. Nelson and Williams (39) have recently found the calcium output of four healthy men on normal unrestricted diet to range from .68 to 1.02 grams of calcium per day. Here as in the case of protein the rate of metabolism to be expected in a normal man on unrestricted diet and well fed, according to American standards, runs from 50 to 100 per cent above the amount which would probably suffice to meet the actual requirement. On sixty-three experiments with ten subjects, (six men and four women), showed calcium outputs ranging from .27 to .78 and averaging .45 gram calcium per man per day. These were all based on uniform weight of 70 killigrams per person.

Kellener recommends feeding one half ounce of common chalk daily to calves on milk based on the studies with pigs by Hart, McCollum and Fuller of the Wisconsin Station. It is reasonable to recommend one half ounce of ground rock phosphate given daily to calves in place of chalk or ground bone.

Lusk (40) also emphasizes the importance of a diet rich in calcium for pregnant women, especially during the last ten weeks of pregnancy when the fetus is storing calcium at a rapid rate.

Forbes and Beegle (41) in studying the mineral metabolism of the milch cow found a heavy loss of body calcium, notwithstanding the fact that the food was believed to supply liberal amounts of all essential elements. According to Forbes it may be necessary to continue high calcium feeding for some time after the cessation of lactation, in order to replace the calcium lost during heavy lactation and during gestation.

The Influence of Function on Calcium Requirement of Animals. Steenbock and Hart (42) state that the level of lime intake necessary for maintenance is dependent upon the functional activity of the various organs of the body. A daily intake of about .3 grams of CaO per 100 pounds body weight covered the metabolism losses of a mature barren pig. From .4 to .5 grams of CaO per 100 pounds body weight covered the loss of a mature dry goat. These figures are not absolute and general, but vary with the character of the ration.

The mamary gland during its activity constitutes a severe drain upon the skeletal lime supply during periods of insufficient lime assimilation and during periods of

insufficient phosphorus assimilation, it indirectly causes a waste of lime from the skeleton. The above authors state that an allowance of one gram of lime in the ration per pound of milk produced by a cow should theoretically be ample. This is in addition to the maintenance requirement. But twice this amount is better and safer.

The above author concluded that the walls of the intestine with normal secretion may cause the loss of a sufficient amount of lime to lower its coefficient of digestibility during periods of sufficient lime ingestion. Also that under normal conditions with a low lime ingestion the usual intestinal losses may in themselves be the cause of a negative lime balance. They state also that liberal assimilation of nitrogen does not imply an assimilation of lime even when the animal's supply of lime is considerably depleted. These are separate and distinct functions of the elementary tract.

Source of Minerals for Dairy Heifer. In the case of cows and other herbivorous animals, dependence for minerals rests almost entirely upon the roughage that is used. The character of the roughage with reference to its content of mineral matter is becoming of increasing importance. It has been demonstrated very clearly that a cow receiving a dry roughage low in lime content and supplemented with grain may abort her calf. This situation has been demonstrated time and time again with the straws which are generally low in lime. On the other hand, if to such a ration a certain amount of lime salts are added there is marked improvement in the character of the offspring but the offspring produced are not as fine as those produced when the roughage is a natural one rich in lime, such as clover or alfalfa hay. Here again is where the soil is the dependent factor because the plants growing on an acid soil are low, in fact very low in lime content. The alfalfa and clovers are very sensitive to soils low in lime and will not grow. In this case it is necessary to add lime to the soil and also to the ration of cows until the lime content of the soil is raised.

The grains form a large source of phosphorus for animals. They are sufficiently high in this element to supply an adequate amount, but they are exceedingly low in calcium.

The Reason Cows Need An Ample Supply of Calcium.

As has been pointed out lime is the main constituent of bone and for this reason it is necessary to keep up the strength of the bones. Cows fed on rations high in lime are not so apt to have broken bones as those fed on rations lacking in this element.

Lime is a vital constituent of milk, and heavy milk production brings about a very heavy drain on the lime of the body of the cow. According to Slipher (43) the annual milk production of the average milch cow (4,000 pounds) contains as much calcium as is found in 150 bushels of wheat or 300 bushels of corn. This amount is equivalent to a lime exhaustion represented by twelve acres of wheat or corn. This heavy depletion of lime asset of the soil makes it doubly important that lime be added to the soil and to the ration of a heavy producing cow.

Lime Essential to Reproduction and Vitality.

Experiments carried on at the Wisconsin Experiment Station have shown that cows fed on rations low in lime give birth to dead offspring and often inmature offspring. Feeds such as alfalfa which carry a good proportion of calcium have been found to be very efficient roughage for reproducing cows.

Normal offspring of good weight and vigor are obtained from such hays. A very good example of a region having soil well supplied with lime is to note that the blue grass region of Kentucky is noted for its nutritious grass and remarkable horses. This probably due to the fact that the soil of Kentucky is very rich in lime and hence the grasses are higher in lime content.

Lime in Rations Increases Feeding Gains. At the North Carolina Experiment Station lime used in mineral mixtures assisted in increasing in the feeding gains of hogs. Hogs which were fed with mineral supplements gained .66 pounds per day as against .46 pounds when the mixture was omitted from a ration otherwise identical. This larger gain was made at lower cost for feed. If this can be brought about in hogs why would it not be very important in obtaining maximum growth of dairy heifers? We want our dairy heifers large and strong in as short a time as possible, that is providing the cost of such operations is not in excess of long time growth of feeding on a lower plane.

Growth is a subject that is not very well understood because it is not known just what causes it. But it is known that the growth impulse lies for the most part in the skeleton of the animal. It is also an established fact that the rate of growth at the time of fertilization of the egg is very rapid and this rate declines very rapidly until finally it stops entirely.

Minerals, especially calcium and phosphorus, play an important part in animal nutrition because they are the main constituents of the bones and they also add in the maintenance of a slight alkaline condition of the body and blood. In the maintenance of a slight alkaline condition each day a certain amount of these minerals are metabolized and excreted from the body. If the amount of calcium and phosphorus necessary in the body and necessary to growth of bone is to be maintained an equal and large enough amount of these minerals must be supplied in the feed.

The majority of investigators have found that rickets is a disease that is due to a deficiency of the elements calcium and phosphorus in the diet. This means that enough calcium or phosphorus has not been supplied

to keep the body in equilibrium; that is the amount of these minerals metabolized and excreted was in excess of the amount supplied in the feed. It has also been developed that there is a factor termed vitamine "D" that aids the animal in the retention of calcium. If this factor is supplied, the animal's efficiency in the use of calcium is much increased.

Tetany is a disease that investigators have found to be due also to a deficiency of calcium in the ration. In the case of tetany the muscles and nerves suffer due to a deficiency of this element. The proportion of potassium to the calcium in the muscles and nerves becomes much larger and the potassium sets up irritability causing tetany.

The animal body has been found to contain about two per cent of calcium which means that the calcium requirement is relatively high. It is computed that it is necessary to supply twenty-one grams of CaO and eighteen grams of P_2O_5 per day to the growing calf during the first year.

EXPERIMENTAL WORK

Object of Experiment

The importance of mineral elements in the nutrition of farm animals has not until within the last seven or eight years received the attention which it deserves. It is just within the last three or four years that any special attention has been called to the possibility of a deficiency of calcium and phosphorus in the ration of dairy cows. It has long been a recognized fact that cattle should receive an abundance of salt but no attention has been placed on the other mineral elements. Perhaps it has not been necessary to pay any attention to these elements until recently because the soil of America is fairly new in point of years as compared with that of European countries and the supply of lime in the soil was large enough to give the crops grown a comparatively high content of lime. But the lands now are becoming depleted in lime and this makes the crops grown very low in calcium and when these crops are fed to livestock they become determining factors in growth, reproduction and production.

It is the object of this experiment to determine the exact effect of a ration low in lime, but otherwise

entirely adequate, on growth and health of dairy heifers. In experiments conducted by Eckles on the effect of a ration low in calcium the ration was derived almost entirely from the corn plant. It has been shown time and time again that the corn plant does not make a ration entirely adequate for normal growth. In this experiment we have endeavored to eliminate all the possible chances of error and to make the ration complete in every respect except that it is very low in calcium.

A great deal of stress is being laid on the amount of calcium that animals should receive, and it is the object of this experiment to determine whether this, or other factors closely connected with calcium are the determining ones.

Plan of Experiment

Two calves, when old enough to eat grain, were fed a ration made up of the following grains which are low in calcium. Yellow corn was used to furnish energy and vitamine "B"; rice to furnish energy alone; butterfat to furnish vitamine "A"; straw treated with HCl to furnish

roughage; peanuts to furnish protein and vitamine "B". Minerals minus calcium and distilled water were also fed.

Each calf was run in metabolism crate for ten days before feeding potatoes and for ten days while receiving potatoes.

The alkaline reserve was determined from time to time.

The effect on alkaline reserve of exercise after confinement in metabolism crate was determined.

Choice of Animal. Two grade Holstein heifers were used in this experiment.

Care, Shelter and Feeding. The animals were fed and handled by a competent feeder under the supervision of the writer. They were kept in individual stalls in a small experimental barn and allowed to exercise in a lot which was free from edible material. Shavings were used for bedding.

During the metabolism period the feed was all weighed on balances graduated in grams. During these periods the writer weighed and fed all feed. During the rest of the time milk scales were used graduated to tenths of pounds. The minerals used were always weighed on the gram balances.

The following was the mixture used: peanuts, rice and corn. The proportions of each were varied as time went on and rate increased. The butterfat was always kept at five per cent of the ration. Straw treated with HCl was used as a roughage until potatoes were fed. Minerals in the form of sodium phosphate, sodium carbonate and magnesium phosphate were fed at different intervals as indicated in the tables showing the amount of feed consumed.

The butterfat was added to make the ration adequate in vitamine "A". The yellow corn and peanuts furnished an adequate amount of vitamine "B" , and as vitamine "C" is not absolutely necessary to normal growth no attention has been paid to the amount of it in the ration.

In experiments carried on by Daniels and Laughlin (44) in feeding peanuts they found that in feeding rats the peanut needs only to have added suitable inorganic elements and fat soluble food accessory to make it a complete food. The proteins of the peanut furnish the essential amino acids in sufficient amounts for normal growth and reproduction when fifteen to eighteen per cent protein levels are fed. Peanuts were found to be lacking especially in calcium, potassium, magnesium and sulphur.

Corn and rice were added to the ration to furnish energy. One hundred pounds of corn furnishes 88.88 therms and rice furnishes 77.33 per hundred pounds.

These calves were fed twice daily. Distilled water was used, no tap water being given after the first month of the experiment.

Collection of Experimental Data

Weighing. Each animal was weighed three days in succession at the first weight period of each month and once at intervals of ten days thereafter. The average of the three days weighings was used as a true weight of the animal. The weights were taken early in the morning before feeding or watering.

Measurements. The following measurements were taken the first of each month: height at rump and highest point of withers; circumference of chest just behind the shoulders; also, depth of chest; greatest circumference taken at largest point of middle; width at hoofs and thurls; length of rump and length from point of shoulder to hook point.

Record of Feed. Feed consumed was recorded each day on a sheet provided for that purpose.

Record of Growth: The weights and measurements were taken at the intervals mentioned above.

Health Observations: The animals were observed every day by the feeder and writer. The body temperatures were taken each day as a guide in recording the health of the animal.

Photographs: Photographs were taken from time to time at a place especially adapted for that purpose, having a background divided off into six inch squares. The background for the later photographs was divided into ten centimeter squares.

Metabolism: The animals were placed in the metabolism crate, the time being observed, and were removed at the same time ten days later. The animals were weighed and alkaline reserve taken before they were placed in the crate. After the animals were placed in the metabolism crate all intake and outgo were carefully weighed on balances graduated in grams.

Analysis: A representative sample of the feed to be received each period was run for calcium and phosphorus. The feces and urine combined were weighed each day or in some cases two days. This was thoroughly mixed and a sample taken. The per cent of moisture was determined each time the feces and urine were weighed. This gave the amount of dry matter excreted. The same amount of excreted matter of each day was put in a container so at the end of a ten day period the composite sample was complete and calcium and phosphorus determinations were made from this sample.

The modified McCrudden Method for analysis of calcium was used and the standard American Association of Chemists Method was used for phosphorus.

Alkaline Reserve of Blood. The alkaline reserve was taken from time to time and before the calf was placed in the metabolism crate; also, immediately after removing from crate. The animals were given moderate amounts of exercise immediately after removing from crate to determine the effect of exercise on the alkaline reserve.

Experimental Data

Two calves were placed on this experiment October 18, 1922 and will continue as long as possible to determine the effect of a low calcium ration on reproduction and production in addition to health and growth. These two calves are designated by numbers 208 and 211. 208 was born June 26, 1922 and 211, July 14, 1922.

Observations of Growth and Health. Both animals continued to gain in weight at a normal rate until the second month of the experiment when they both continued to gain, but very slowly, as is shown in Table I and II.

The height growth of 208 was under normal at the start of the experiment and continued that way until the writing of this thesis. 211 was slightly above normal at the beginning of the experiment and until the beginning of the second month when she fell slightly below normal and continued so.

The depth of chest, circumference of chest and greatest circumference show practically no change after the first two months of the experiment. In other words the long bones which have been growing at the expense of the rest of the body are the only ones which have continued to make normal growth. This conforms with Mendel's theory

that the skeleton grows at the expense of the rest of the body. After two hundred and ten days on the experiment 211 showed stiffness of joints and a very thin appearance. 208 while not as bad as 211 also showed similar conditions.

After one hundred and ninety-five days on the experiment heifer 208 was fed potatoes in the place of straw for roughage and showed a marked improvement in appearance immediately. The hair became glossy and smooth and the general appearance was much improved. But in the case of 211, who was fed potatoes at the end of two hundred and fourteen days, the change was not so marked.

At the end of the experiment heifer 211 appeared to be in quite a healthy condition. They were both very much below normal in weight and showed a lengthy condition, that is they did not show normal constitution nor normal middle, but except for this they were otherwise normal.

DISCUSSION OF EXPERIMENTAL DATA

The Effect of a Ration Deficient in Calcium on Body Weight. Both animals in this experiment showed a marked decline in per cent normal growth as shown by weight from the beginning of the second month until they started to receive potatoes. Cal 208 showed a marked increase at this time, her general condition becoming much improved. This may be due to the fact that the succulence offered in the form of potatoes increased the appetite thus increasing the amount of feed consumed. The incfeased gain, however, was not of long duration, lasting four ten day periods when a marked decline was again shown. In the case of Calf 211 the period of gain following the feeding of potatoes was only one ten day period in length when she continued to decline.

It seems from the observations of both animals that there are periods at which they showed marked increase in appetite and at these periods the gain in weight was much greater. These periods seemed to come about at the same time in the case of both animals. The calcium deficiency seems to make the animals lose their appetite and hence a falling off in gain in weight or even a loss in weight. These results do not conform with those of Aron and Sedauer (45) who state that calcium requirement is at least 1.2 per cent of the augmentation of body weight, but in general the organism is only slightly effected by calcium deprivation. Increase in weight occurs normally, only at times are digestive and nervous disturbances evident. The injury rests almost entirely with the bony tissues. With the calves in this experiment the increase in weight has not occurred normally but digestive and nervous disturbances have been known to some extent. The feces were at all times liquid.

Each animal was run in the metabolism crate two ten day periods and in all cases showed negative calcium and positive phosphorus balances. This conforms with the results of Patterson (46) who conducted an experiment with rabbits fed on oatmeal and cornmeal, a diet which led to calcium starvation. The ratio of calcium in the total ash in the blood remained about the same as in normal animals. The ratio of calcium to the total minerals in the bone, however, was not consistent and when the animal was placed on a diet poor in calcium there was an actual loss of it from the body.

The Effect on Measurements of a Ration Deficient in Calcium. The height measurements have shown almost normal growth throughout the experiment. But the depth of chest, circumference of chest, greatest circumference, width of thurls and hooks, and length of rump have all fallen below normal. The normal figures for these measurements have not been published as yet. All these measurements have been taken once a month on all growing heifers and bulls at the Michigan Agricultural College. The probable reason for the growth of the long bones is that it is the tendency of the animal for self preservation and the long bones are more effective for this than any others.

The Effect of Exercise on Alkaline Reserve After Confinement. In all cases, except one the alkaline reserve, a marked drop after exercise was noted, as in shown in the table. In one case with calf 208 the alkaline reserve was higher after exercise than it was before. This is probably due to the fact that in this case the calf was given a longer and more strenuous exercise than in any other cases and the proteins were brought into action and produced alkaline compounds in the blood, thus neutralizing the acid produced so that the alkaline reserve did not go down. If this animal had not been exercised so long she probably would have shown a drop in alkaline reserve.

Effect of a Ration Low in Calcium on Calves as Compared to Those on a Normal Diet. Calves 213 and 214 were given a normal diet which consisted of whole milk, whole corn and oats and alfalfa hay up until two months of age when the skim milk was substituted for the whole milk. They received this ration until six months of age when the skim milk was taken away, silage, alfalfa hay and a mixture of ground corn, ground oats and cotton seed meal being fed for the rest of the period. The milk and alfalfa make this ration relatively high in minerals.

Calf 213 was born July 27 and 214, July 28, 1922. They are somewhat younger than calves 208 and 211 used in this experiment. It will be noticed that they are somewhat smaller at the beginning of the experiment as is shown in photographs 3 and 4, but at the end of the experiment are considerable larger throughout. Calves 213 and 214 are not used as checks but simply to compare a calf receiving a normal ration with one receiving a ration low in calcium.

Effect of a Ration Low in Calcium on the Body Temperature. The temperatures of the animals were taken every day throughout the experiment and it was found that the temperatures remained normal not being influenced by the ration. The fluctuations in temperature were no more than those found in a normal calf.

Evidences of Tetany and Rickets. There were no evidences of tetany shown by these calves. They at no time showed any tendency towards convulsion even when they became excited. From this can be seen that the calcium content of the blood and tissues must have been high enough to prevent tetany. This calcium supply must have come from the bone because the feed at no time supplied enough calcium to equal the requirements as set down by experimentors. Kellner computes the calcium and phosphorus retention of the growing calf as 21 grams of CaO and 19 grams of P_2O_5 per day during the first year and states that the food should contain 40 to 60 grams of each. Weiske studied the metabolism of calcium phosphate with two five to six months old calves. One calf retained about one half of the 12 grams of calcium phosphate added to the ration per day while the other did not retain any of the added calcium phosphate, the difference in results apparently being due to the greater consumption of the basal ration by the latter calf, the food furnishing the entire calcium and phosphorus requirements. Weiske considered that 16.85 grams of CaO and 21.88 grams of P_2O_5 probably represents the full daily requirements of calves for these elements.

From the review of literature it can easily be seen that the calcium content of the ration used in this experiment was very low when compared to the normal requirement.

There were some very slight evidences of rickets. The animals showed slightly swollen joints and when walking or running appeared to be slightly stiff in the joints but these were the only evidences noted that indicated the possibility of a deficiency of calcium in the bones.

Discussion of Results

The results of this experiment indicate that calcium is not as necessary to the maintenance of normal height growth and health as has been previously pointed out. These heifers while not in perfect condition or exactly normal in every respect are in fair condition and do not show any indications of coming down with tetany or rickets, the two diseases due to a deficiency of calcium.

The poor condition in respect to weight, development of middle, constitution, etc. is in all probability due to a lack of food consumption rather then the lack of calcium in the ration. If the animals had consumed more food they probably would have maintained normal growth in every respect. But on the other hand the observations and results seem to indicate that the deficiency of calcium in the ration causes the animals to lose their appetites and hence they are unable to maintain normal growth in every respect because they did not consume enough feed.

The feeding of potatoes had no effect on the amount of calcium and phosphorus excreted. The succulence offered in potatoes, however, increased the amount of feed consumed and hence an increase in rate of weight growth for a time.

The effect of moderate exercise on alkaline reserve was clearly shown. Exercise decreased the alkaline reserve quite markedly in all except one case. The reason for this has been pointed out.

Conclusions

(1) Calcium is not as necessary for maintenance of growth and health as has been previously pointed out.

(2) The animals maintained practically normal growth in height throughout the experiment.

(3) The poor condition of the animals in this experiment is due to a lack of food consumption rather than a deficiency of calcium in the ration.

(4) The feeding of potatoes has no effect on the calcium excreted or retained.

(5) Moderate exercise has a marked effect on the alkaline reserve of animals after confinement.

(6) A deficiency of calcium in the ration has no effect on the body temperature.

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A P P E N D I X

Table 1. **Calf 208**

Ten day period	Grain Mixture	Hay	Potatoes	Nutrients Required: Digestible Crude Protein	Nutrients Required: Net Energy	Nutrients Received: Digestible Crude Protein	Nutrients Received: Net Energy	Gain in Weight
1	50	20		.69144	4.0721	.62500	4.2560	21
2	37	20		.70300	4.1220	.77100	5.0580	9
3	42	20		.71000	4.1640	.77100	5.0580	7
4	37.5	42		.71300	4.1820	.59300	4.2150	3
5	56	33		.72150	4.2330	.66600	5.0580	8.5
6	61.5	20		.73000	4.2840	.66600	5.0580	8.5
7	43.5	20		.73000	4.3020	.44520	3.5830	3
8	41.5	20		.73000	4.2840	.45400	4.2320	-3
9	24	20		.73700	4.3260	.31440	2.0232	7.5
10	40	20		.74800	4.3920	.45400	4.2320	10.5
11	39.5	20		.75000	4.4040	.45400	4.2320	2
12	31.5	20		.75000	4.4040	.38860	3.4732	0
13	54.5	20		.76254	4.5813	.59300	5.0750	19
14	60	20		.76650	4.6372	.69600	5.9180	6
15	60	20		.76914	4.6746	.69600	5.9180	4
16	60	20		.77376	4.7399	.69600	5.9180	7
17	46.5	10		.76584	4.6279	.74260	5.9980	-12
18	72	00		.75792	4.5159	.84870	6.6440	-12
19	28		162	.76122	4.5626	.31652	4.1489	5
20	36		204	.77046	4.5932	.57688	7.1306	14
21	32		202	.78300	4.8705	.57688	7.3807	19
22	32		176	.80082	4.1384	.43860	7.8540	29
23	40		200	.80049	5.1383	.41660	7.8120	-1
24	22		200	.80049	5.1383	.23903	5.9106	-42
25	24		200	.77376	4.7398	.25576	6.1272	-5.3

Table 2. Calf 211

Ten day Period	Grain Mixture	Hay	Potatoes	Nutrient Required: Digestible Crude Protein	Nutrient Required: Net Energy	Nutrients Received: Digestible Crude Protein	Nutrients Received: Net Energy	Gain in Weight
1	50	00		.64112	3.9041	.53000	4.8750	0
2	60	20		.67240	4.0086	.65800	5.9180	23
3	42	20		.69144	4.0721	.44720	4.4060	14
4	37.5	42		.69552	4.0857	.44370	4.9672	3
5	56	33		.70400	4.1280	.62990	6.1398	7
6	61.5	20		.70800	4.1520	.67610	6.0445	4
7	43.5	20		.72700	4.2660	.52100	4.5271	19
8	40.5	20		.72800	4.2720	.45731	4.9910	1
9	32	20		.74000	4.3440	.37392	4.1400	14
10	40	20		.73400	4.3080	.45240	4.9400	-6
11	40	20		.74000	4.3440	.45240	4.9400	6
12	46	20		.74300	4.3620	.51126	5.5750	3
13	52	20		.74100	4.3500	.57012	6.1900	-2
14	60	20		.75330	4.4506	.64860	6.9800	14
15	45	20		.75132	4.4226	.50145	6.4500	-3
16	48	20		.75594	4.4880	.52488	5.6700	7
17	60	18		.75660	4.4133	.67860	6.5500	1
18	50	10		.75066	4.4973	.49050	5.1300	-9
19	48	00		.73100	4.2900	.47088	4.8960	-20
20	27	00		.75396	4.4599	.26487	2.7540	25
21	45	00		.75000	4.4040	.44045	4.5900	-6
22	53	10		.74500	4.3740	.62930	5.8360	-5
23	25		166	.74500	4.3740	.61200	5.8100	0
24	16		191	.74500	4.3740	.60120	5.7820	0
25	32		200	.74500	4.3740	.63120	5.9000	17

Table 3. Description of Calves Used in Experiment.

Description	Calf 208	Calf 211
Age at beginning of experiment	124 days	106 days
Age at end of experiment	375 days	365 days
Weight at beginning	248 lbs.	232 lbs.
Weight at end	355.7 "	354 "
Percent normal weight at beginning	96.8	102.5
Percent normal weight at end	64.4	64.2
Height at beginning	91.5	95.0
Height at end	109.8	112.3
Percent normal height at beginning	98.9	103.8
Percent normal height at end	95.9	98.8

Table 4. Measurements of Calf 208 on a ration Low in Calcium as Compared with Calf 213 on a ration High in Calcium

Date	Height at Withers		Height at Rump		Depth of Chest		Width of Thurls		Width of Hooks		Hooks to Shoulders		Length of Rump		Circumference of chest		Greatest circumference	
	208	213	208	213	208	213	208	213	208	213	208	213	208	213	208	213	208	213
Oct. 8	91.6	89.2	100	93.8	40.5	39.5	28	27	25	24	72	63	35	33	109	105	120	111
Nov. 7	97.2	91.3	100	96.5	42.0	40.0	29	29	26.5	24	70	67	35	34	113	106	130	120
Dec. 7	98.6	96.0	104.5	99.0	44.0	41.5	31	30	26.5	27.5	77	78	37	37	115	115	130	125
Jan. 7	101.5	99.8	106.0	104.2	44.5	45.0	32	32.5	29.	29.	75	80	36	36	119	119	130	131
Feb. 5	103.0	104.5	108	111.	45.5	47.0	32.5	33	28	31	83	85	36	41	124	127	132	150
Mar. 7	107.5	106.6	110	112.7	46.5	50.5	32.	35	29	33	85	89	40	42	125	135	142	155
Apr. 7	108.0	112.0	112	117.5	49.0	55.0	34.5	37	30	35	90	93	41	45	125	140	135	164
May 7	106.8	112.8	113.2	119	50.0	55.5	34.	37.5	29.5	36	82	94	40	43	125	146	136	172
June 6	108.2	117.5	114.5	119	49.5	54.5	35	40	30	38	84.5	100	39.5	45	127.5	155	136.5	180
July 6	109.8	118.0	115.8	124	49.5	57.0	35.5	41	30.5	40	87	101	39	47	130	155	137	179

Table 5. Measurements of Calf 211 on a Ration Low in Calcium as Compared with Calf 214 on a Ration High in Calcium.

Date	Height at Withers		Height at Rump		Depth of Chest		Width of Thurls		Width of Hooks		Hooks to Shoulders		Length of Rump		Circumference of chest		Greatest circumference	
	211	214	211	214	211	214	211	214	211	214	211	214	211	214	211	214	211	214
Oct. 8	93.2	88.8	101	93.5	39	37	29	28	25.5	21.5	71	66	33	32	108	101	115	107
Nov. 7	97.2	94.8	104	98.8	44	40	27.5	29.5	27.0	27.0	70	69	35	33	112	109	132	128
Dec. 7	101.0	98.3	106.3	101.7	42	41.5	31	27.5	25.5	27.0	77	79	37	37	113	115	123	120
Jan. 7	102.5	102.8	108.	107.0	43	46	31.5	33.5	28	31.5	75	80	37	31	117	120	130	140
Feb. 5	104.3	107.0	112.5	112	45	47	32.5	34.5	28	30.5	80	80	36	39	120	130	132	152
Mar. 7	108.8	111.6	113.5	116.2	46	49.5	33	37.5	29.5	34.5	84.9	90	38	42	122	137	138	160
Apr. 7	108.0	114.0	115.5	118.0	49	54.	34	39.5	29.5	36.5	88	94	40	44	122	141	134	166
May 7	109.0	117.0	116.5	121.5	48	55.5	34	39.5	29.5	36.0	87	97	41	45	123	150	132	173
June 6	112.0	118.5	118	122	50	58	33.5	41.5	30	39	85	96	40	46	124	154	130	173
July 6	112.3	120.3	119	124.1	49.5	58	30	43	29	40	85	101	41	47	128	160	142	186

Table 6. Calf 208

Date	Weight Feed Consumed	CaO received	P_2O_5 received	CaO excreted	P_2O_5 excreted	Alkaline Reserve
	gms.	gms.	gms.	gms.	gms.	
April 11	1500	1.488	19.3737			
April 12	3000	2.976	38.7474	6.6983	9.555	66
April 13	3000	2.976	38.7474	8.2740	11.804	
April 14	3000	2.976	38.7474	8.6290	12.314	
April 15	3000	2.976	38.7474	8.6510	12.316	
April 16	3000	2.976	38.7474	6.0470	8.627	
April 17	1500	1.488	18.3737	6.4140	9.152	
April 18	1500	1.488	19.3737	7.2580	10.359	
April 19	3000	2.976	38.7474	5.2700	7.519	
April 20	1500	1.488	19.3737	6.1890	12.615	
April 21				6.2250	12.687	60

Total CaO intake ten days - 23.808
Total CaO outgo ten days - 69.635
Negative Cao balance - 35.827

Total P_2O_5 intake ten days - 309.9792
Total P_2O_5 outgo ten days - 106.9480
Positive P_2O_5 balance - 3.0312

Table 7. Calf 211

Dates	Weight Feed Consumed Grain	Straw	CaO Received	P_2O_5 Received	CaO Excreted	P_2O_5 Excreted	Alkaline Reserve
	gms.	gms.	gms.	gms.	gms.	gms.	
May 16	900		.7669	4.723			64.5
May 17	1800	700	2.1258	9.704	3.059	8.301	
May 18	1800	800	2.2108	9.802	2.546	6.908	
May 19	1800	900	2.2954	9.651	1.957	5.311	
May 20	1800	600	2.1415	9.651	2.321	6.308	
May 21	1800	600	2.1415	9.542	2.330	6.312	
May 22	1800	-	1.5338	9.542	2.678	7.265	
May 23	1800	-	1.5338	9.542	4.059	11.016	
May 24	1800	-	1.5338	9.542	3.138	8.456	
May 25	1800	-	1.5338	9.542	5.042	12.684	
May 26	900	-	.7669	4.723	6.793	17.435	58.0

Total CaO intake ten days - 17.8171
Total CaO outgo ten days - 33.9230
Negative CaO balance - 16.106

Total P_2O_5 intake ten days - 95.964
Total P_2O_5 outgo ten days - 89.996
Positive P_2O_5 balance - 5.968

Table 8.

Calf 208

Date	Weight Feed Consumed Grain	Weight Feed Consumed Potatoes	CaO received	P_2O_5 received	CaO excreted	P_2O_5 excreted	Alkaline Reserve
	gms.	gms.	gms.	gms.	gms.	gms.	
June 4	-	3000	.2404	14.4152	-	-	73
June 5	1410	3535	1.4830	22.5140	2.819	10.794	
June 6	2000	6120	2.1960	28.9819	1.991	7.625	
June 7	1000	3000	1.0925	19.6640	1.991	7.625	
June 8	2000	6000	2.1870	28.8280	3.640	13.896	
June 9	2000	6000	2.1870	28.8280	3.640	13.896	
June 10	2500	6000	2.6136	31.4525	3.194	12.236	
June 11	1900	6000	2.1022	28.3027	3.194	12.236	
June 12	1900	6000	2.1022	28.3027	5.329	20.406	
June 13	1800	6020	2.0184	27.7772	5.329	20.406	
June 14	-	3000	.2402	14.4152	15.207	58.228	67

Total CaO intake 10 days - 18.4625
Total CaO outgo 10 days - 46.3340
Negative balance - 27.8715

Total P_2O_5 intake 10 days - 262.9769
Total P_2O_5 outgo 10 days - 177.3480
Positive balance - 85.6289

Table 9. **Calf 211**

Date	Weight Feed Consumed Grain	Potatoes	CaO received	P_2O_5 received	CaO excreted	CaO excreted	Alkaline Reserve
	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	
June 26	700	3000	.7691	17.5972			71.5
June 27	2100	5000	2.0783	27.5679	1.7915	7.3639	
June 28	2400	6000	2.3916	30.4507	1.7915	7.3639	
June 29	900	6000	1.1115	22.5664	2.5039	10.2921	
June 30	2100	4000	2.0211	16.2620	2.5039	10.2921	
July 1	3000	6000	2.9018	23.5992	2.5229	10.5286	
July 2	800	6000	1.0259	12.0391	2.5229	10.5286	
July 3	800	6000	1.0259	12.0391	4.1972	17.2520	
July 4	1000	2500	.9962	8.5194	1.9301	7.9334	
July 5	2500	6300	2.4934	21.3638	1.9301	7.9334	
July 6		3000	.1717	3.9178	7.5682	30.6969	70.5

Total CaO intake 10 days - 16.9865
Total Cao outgo 10 days - 29.2622
Negative CaO balance - 12.2757

Total P_2O_5 intake 10 days - 195.9226
Total P_2O_5 outgo 10 days - 120.1849
Positive P_2O_5 balance - 75.7377

Table 10. Effect of Exercise on Alkaline Reserve After Confinement.

Date	Calf Number	Alkaline Reserve before Exercise	Alkaline Reserve after Exercise
April 21	208	60	55
May 26	211	58	50
June 14	208	67	68
July 6	211	70.5	64

Table 11. Average Body Temperatures for Each Ten Day Period.

Period	Average Temperature Calf 211	Average Temperature Calf 208
1	101.65	101.57
2	101.30	101.25
3	101.19	101.66
4	101.49	102.08
5	102.53	102.17
6	102.41	101.50
7	100.98	101.38
8	101.54	101.75
9	100.85	101.58
10	101.38	101.23
11	101.54	101.49
12	101.24	101.25
13	101.25	101.41
14	101.50	101.14
15	101.48	101.13
16	101.16	101.07
17	101.41	101.04
18	101.14	101.81
19	101.13	101.35
20	101.24	101.41
21	100.92	101.28
22	101.22	101.37
23	101.18	101.43
24	100.91	101.10
25	100.91	101.43
26	100.95	100.92

Table 12. Digestible Crude Protein and Net Energy Values Per 100 Pounds for Ruminants.*

Feed	Digestible Crude Protein	Net Energy
Corn	6.9	85.20
Rice	4.7	77.33
Peanut kernel	24.1	109.04
Wheat straw	0.7	7.22
Potatoes	1.1	18.27
Timothy hay	3.0	43.02
Alfalfa hay	10.6	34.33
Oats	9.7	67.56
Cow's milk (whole)	3.3	29.01
Cow's milk (centrifugal skimmed)	3.6	14.31
Butterfat	.0	422.20
Corn silage	1.1	15.90

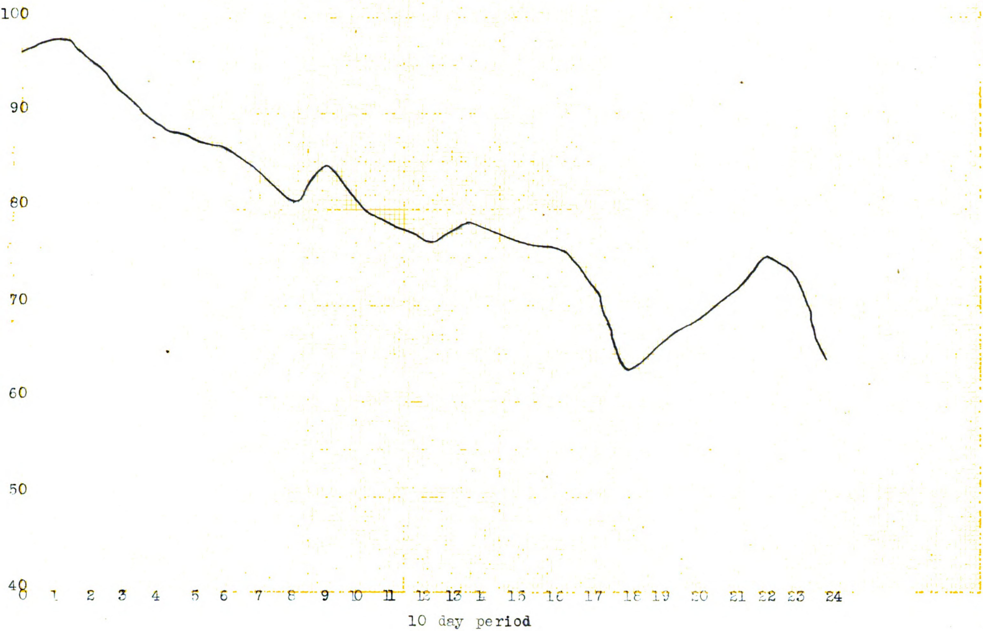
*Armsby, H. P. The Nutrition of Farm Animals (1917). Pgs. 715-721.

Table 13. Mineral Elements of Feeding Stuffs - Per 100 Pounds of Dry Substance.*

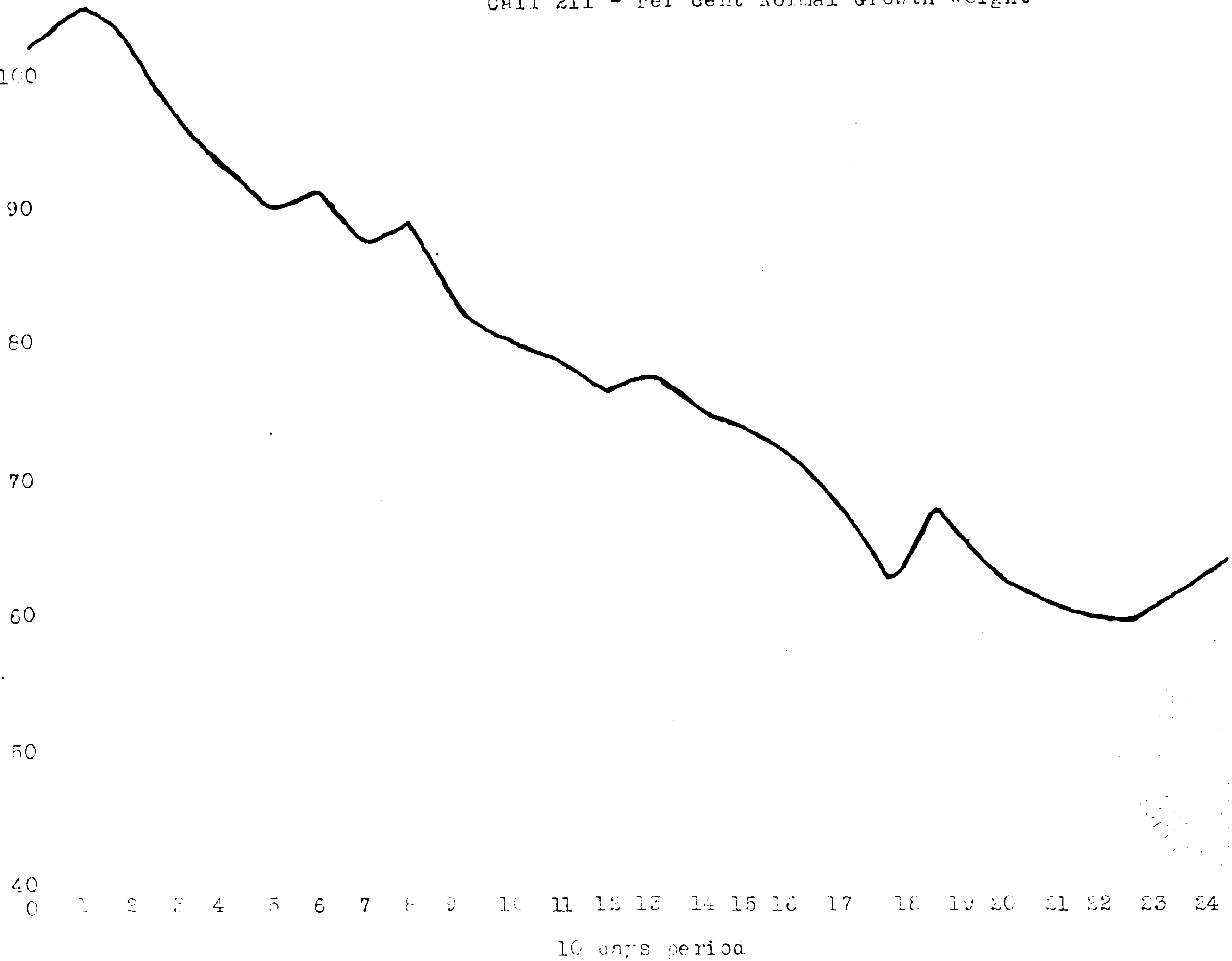
Feed	Calcium	Phosphorus
	Percent	Percent
Corn	.014	.303
Rice	.009	.104
Peanut kernel	.068	.399
Wheat straw (not extracted with HCl)	.017	.038
Potatoes	.027	.270
Timothy hay	.192	.123
Alfalfa hay	1.130	.238
Oats	.112	.434
Cow's milk (whole)	1.336	.979
Cow's milk (centrifugal skimmed)	1.336	.979
Corn silage	.507	.102

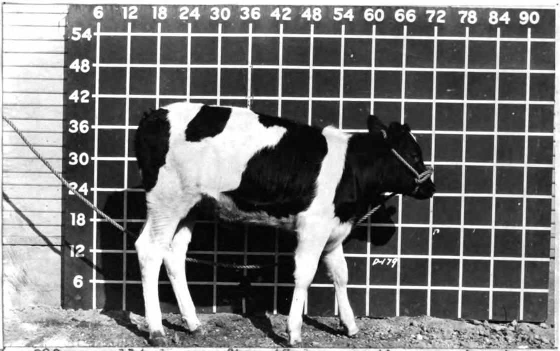
*Armsby, H. P. Nutrition of Farm Animals (1917). Pgs. 723-724.

Calf 208 - Per cent Normal Growth Weight

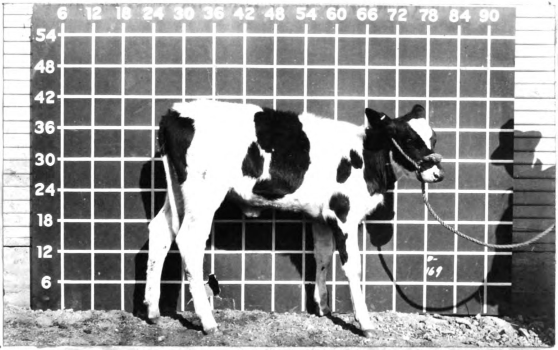


Calf 211 - Per cent Normal Growth Weight

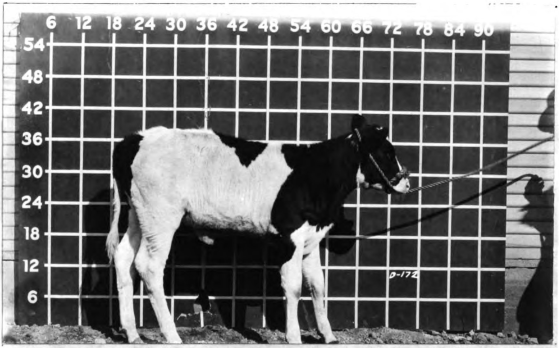




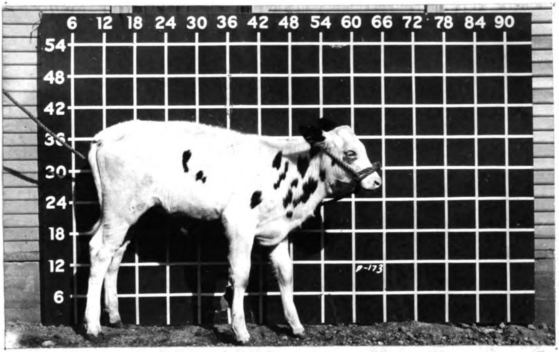
Heifer 208, age 114 days, after 43 days on the experiment.



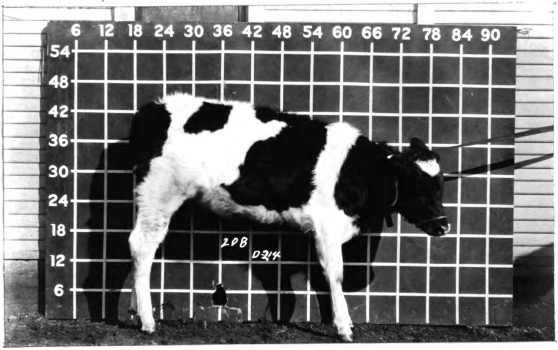
. Heifer 211, age 96 days, after 43 days on the experiment.



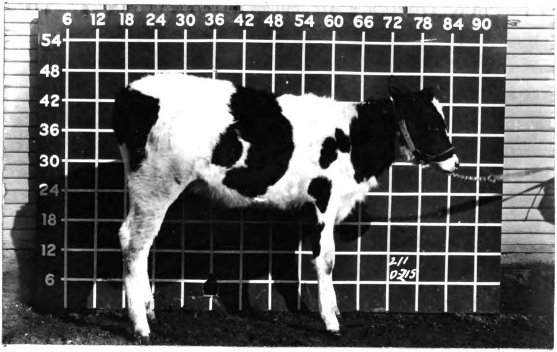
Heifer 213, age 128 days, on normal ration.



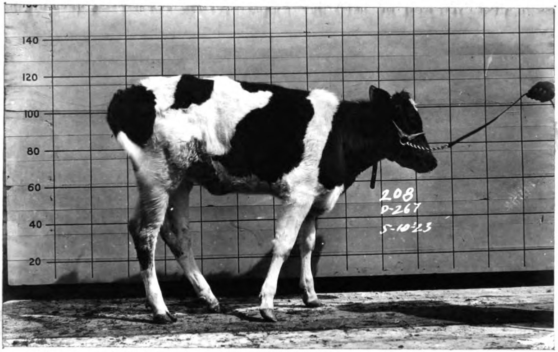
Heifer 214, age 127 days, on normal ration.



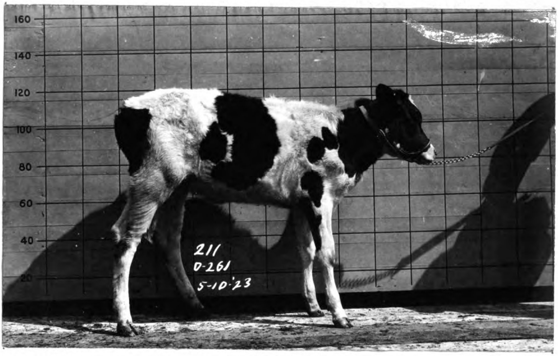
Heifer 208, age 249 days, after 135 days on the experiment.



Heifer 211, age 231 days, after 135 days on the experiment.

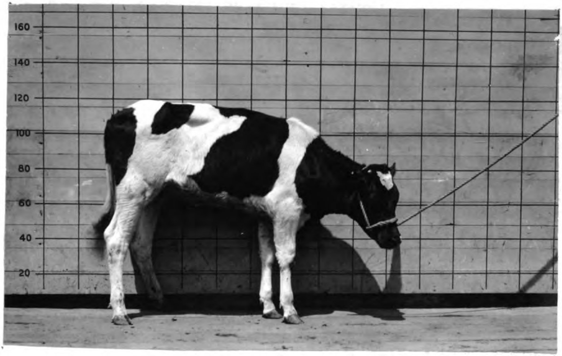


Heifer 208, age 318 days, after 204 days on the experiment.

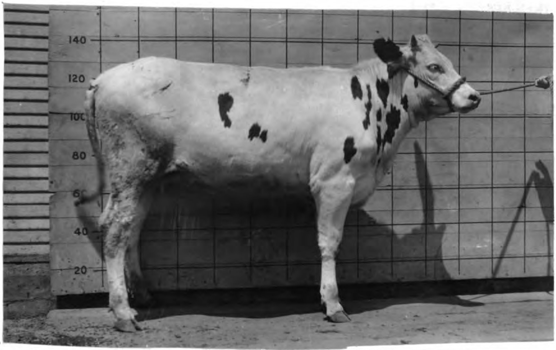


Heifer 211, age 300 days, after 204 days on the experiment.

Heifer 213, age 342 days, on normal ration.



Heifer 208, age 370 days, after 245 days on experiment.



Heifer 214, age 341 days, on normal ration.

Heifer 211, age 359 days, after 245 days on experiment.