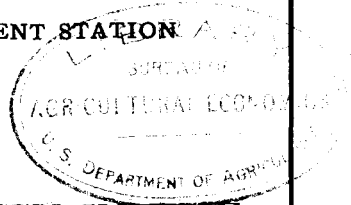


UNIVERSITY OF MINNESOTA
AGRICULTURAL EXPERIMENT STATION



A MINERAL DEFICIENCY IN THE RATIONS OF CATTLE

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A MINERAL DEFICIENCY IN THE RATIONS OF CATTLE¹

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The staff of this experiment station has for several years been cognizant of a dietary deficiency of cattle in parts of western Minnesota. Reports are received each winter, some years more numerous than others, of cattle exhibiting abnormal symptoms, including depraved appetite, or pica. Conditions of this kind are by no means uncommon elsewhere and have been reported by numerous writers. However, the conditions as reported for this region in Minnesota are unusually severe, so bad, in fact, as seriously to interfere with the development of the livestock industry in the areas affected. For this reason a study of the problem was begun in 1923 and is still under way.

REVIEW OF LITERATURE

The occurrence of abnormal conditions of cattle due, presumably, to a mineral deficiency in the ration has been reported from many localities in the United States. Studies of the subject in some detail have been made by the experiment stations of Montana (49) and Texas (43). References to the occurrence of depraved appetite are also found in a number of publications dealing with nutrition and livestock production (50). Many references to the subject may also be found in the columns of agricultural papers, especially in the form of questions from subscribers. These reports indicate that the trouble has long been recognized and is quite severe in Montana and on the coastal plain of Texas. It is also reported from eastern Michigan, the higher altitudes of New York and Pennsylvania, in West Virginia, Virginia, South Carolina, Alabama, Mississippi, and in the irrigated sections of the southwest and inter-mountain region.

Areas where livestock suffer from mineral deficiency appear to be rather common in other parts of the world. In Victoria and New South Wales, Australia, trouble of this nature appears to be of considerable importance as reported by Murphy (39), Guthrie and associates (15), Henry (24), and several others (51). From New Zealand, Aston (1) and Reakes (42) report extended deficiency troubles among both cattle and sheep. They concluded that the cause of the trouble was a shortage

¹ These data are taken in part from a thesis presented to the Graduate Faculty of the University of Minnesota by R. B. Becker in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

of phosphorus and iron in the forage used. Elliott (7) reported outbreaks of osteoporosis among horses in Hawaii as early as 1899. The work of Miles and Feng (36) indicates that osteomalacia is not confined to animals but is common among women in northeastern China, being caused by a deficiency of calcium in the diet. According to Tuff (48), severe mineral deficiency troubles were known in restricted areas in Norway as long ago as 1860.

Mineral deficiency troubles were recognized in Germany at least as long ago as 1861, when Von Gohren (12) referred to troubles of this kind having been especially common in certain regions near the Rhine in 1859. Others who contributed to this subject in the early days were Bauer (4), Nessler (40), and Grouven (14). The most complete report of the troubles of this kind in Germany was made in 1923 by Konig and Karst (31). These authors mention the prevalence for at least 25 years of mineral deficiency troubles with cattle in eight localities in Germany and refer to the occurrence of similar conditions in parts of Switzerland, Austria, and Hungary.

Possibly the most severe conditions of all so far studied prevail in the Union of South Africa. Theiler (46, 47) and associates have published the results of extensive investigations of the widespread and serious difficulties encountered in cattle raising on the veldt as the result of the low mineral content of the feed.

SYMPTOMS

Henry (24) describes the typical symptoms as seen in cattle in Australia as stiffness in the hind quarters; swelling of the joints; a harsh dry coat; dull eyes; unthrifty general appearance; perverted appetite; leg and rib bones easily broken; soft bones in some, brittle in others; decreased milk yields. This statement includes most of the symptoms mentioned by the numerous writers reporting troubles of this kind, altho some emphasize certain symptoms more than do others. Welch (49) has also given a detailed description of the symptoms of the nutritional disorder due to the shortage of minerals which he has observed since 1910 in Montana. He emphasized the bone chewing and the evident craving for something not supplied by the feed, and attributes the high abortion rate on affected ranches to this cause. All writers who have described troubles of this kind mention the greater prevalence following periods of deficient rainfall, and in most cases point out that the symptoms are most severe in the winter season after periods of feeding dried feeds. Cows in milk show the most severe symptoms, followed by young growing animals.

In addition to the symptoms mentioned, Tuff (48) refers to paralysis as a common occurrence. The paralysis usually begins in the rear quar-

ters and spreads throughout the body, death resulting finally if the necessary minerals are not supplied. In rare cases convulsions and fits of frenzy are observed. The tail sometimes becomes quite soft and can be coiled like a rope. According to Tuff, osteomalacia is far less common now than formerly, owing to better feeding practices. The experience of cattle owners has been that reproductive troubles, including sterility and abortion, are much greater when the depraved appetite is most severe. German writers refer especially to breaking of bones, gnawing of wood, licking of stones and dirt, and a loss of appetite.

NOMENCLATURE

These nutritional disorders have received a variety of names, but the symptoms have much in common and suggest a common cause. The terms osteomalacia and osteoporosis are most commonly employed in the literature. In addition various more or less local terms are in use. In the veterinary literature of the United States, the term pica is the most common; others are big-head of horses, bone softening, osteoclastia, enzootic ostitis, and fragilitis osseum, as well as loin disease. European writers use the following terms in addition: Lecksucht, Knochenbruchigkeit, and Nagekrankheit. Africa contributes the term stifziekte, which is sometimes associated with lamziekte; Australia and New Zealand, the terms stiffs, cripples, osseum cachexia of sheep, Winton disease; Tasmania, the term Midland disease. It will be noted that most of the terms used are based upon some one of the common symptoms observed.

INVESTIGATIONS CONCERNING CAUSES

The most complete work yet reported on mineral deficiency disease with cattle is that of Theiler and co-workers (46, 47). The first experiments are reported in earlier publications and all results to May, 1924, are summarized in the two papers to which references are given. They found the fatal disease "lamziekte" to be due to toxic bacterial products which cattle consume when eating decayed flesh and chewing putrid bones. The cause of the craving, pica, or depraved appetite of cattle, which leads to the eating of bones, was found to be lack of phosphorus in the forage. They overcame the depraved appetite through feeding wheat bran, bonemeal, sodium phosphate, or even phosphoric acid, while calcium carbonate appeared to have a detrimental effect.

Aston (1) and Reakes (42) concluded that the severe troubles in New Zealand were to be attributed to the low phosphorus and iron content of the soil and vegetation. Their later reports emphasize the lack of iron as the most important factor. Henry and others who studied the conditions in Australia were convinced that the low phosphorus content of the feeds grown in the affected areas was the real

cause of the trouble. They recommended the use of bonemeal as a preventive. Tuff (48), in Norway, considers a shortage of both calcium and phosphorus as responsible for the severe troubles in that country.

Early German investigators, including Stohmann (45), Karmrodt (29), and Nessler (40), point to a low phosphorus or a low calcium and phosphorus content of the hay as the cause. Frequent mention is made of the use of bonemeal as a cure for the condition. Kellner (30), writing in 1894, takes the same view, giving the analyses of hays from affected farms to show the exceedingly low phosphorus content. Ibele (27) introduces a new view by attributing the mineral deficiency known as Lecksucht to an excess of sulfates in proportion to calcium. König and Karst (31) were inclined to attribute Lecksucht to the alkaline reaction of the hay ash and the excess of sulfates. Few attempts appear to have been made by these investigators to solve the problem through supplementing the rations with various minerals further than by the reported use of bonemeal by livestock owners.

Relation of Mineral Deficient Diet to the Production and Utilization of Cattle

Growth.—Experimental work reported by several authors gives the effects of rations deficient in mineral matter when received by growing cattle. Becker (5) found calves to develop rachitic symptoms on a ration low in available calcium; Eckles and Swett (8) fed a calf a ration low in calcium, resulting at the end of 13 months in stiffness so extreme that the animal walked with difficulty and could barely arise. Recovery followed feeding bonemeal and a forage high in calcium. The rate of growth of this animal was normal until symptoms developed. Theiler (46, 47) reported a marked increase in the rate of growth by the addition of bonemeal to phosphorus deficient diets. Animals receiving this supplement during a certain period gained 105 per cent compared to 60 per cent for check animals.

Fattening.—Theiler also shows striking results in the way of larger gains as well as better utilization of feeds as the result of adding bonemeal to the phosphorus deficient diets. In one experiment the controls increased 21 per cent in weight during a stated period; while the experimental group in the pasture, receiving a supplementary feed of 3 ounces of bonemeal daily, gained 42 per cent. He interprets his results as indicating a need for phosphorus beyond that required for skeletal development. He says: "Cattle on a phosphorus deficient diet do not utilize their feed economically. Even if they eat a lot they waste it and do not give a profitable return in live weight for it." The reports of German writers indicate mineral deficiency troubles as re-

sponsible for large economic losses. Mention is made of losses following especially dry years of as high as half the herd. Undersized animals, low milk production, and difficulty in fattening the animals sufficiently for market are also mentioned.

Reproduction.—Evidence is found in the literature indicating that at least under extreme conditions of mineral shortage serious disturbances occur in reproduction. Tuff states that experience in the badly affected areas of Norway shows unmistakably a relation to reproduction, indicated especially by failure to ovulate. Nessler (40) also made the same observations concerning similar trouble in Germany. These observations made on animals under natural conditions are substantiated by the results of experimental work of Hart and associates (21), who found that rations derived from the oat or wheat plant required a calcium supplement in order to secure normal reproduction. They mention 0.45 per cent CaO in the ration as the lowest limit compatible with reproduction in cattle. Meigs (35) also reports difficulty in reproduction with cows on a low calcium ration. Cows on a ration very low in phosphorus, in an experiment by Jordan (28), showed entire cessation of oestrus.

Composition of Feeds

The investigations concerning mineral deficiency troubles point clearly to a deficient or improperly balanced mineral content of the feeds used as the causative factor. The low mineral content of the feeds in turn appears to be the result of correspondingly low mineral content of the soils which produced the feeds in question. The investigations of this subject have been summarized by Forbes (10).

Data regarding the relation of the available mineral content of the soils to the mineral composition of the forage grown are voluminous but somewhat contradictory. The general opinion seems to be that on mineral soils variations in the mineral composition of grain and seeds at most are too small to be of much significance. Ames (3), for example, found wheat grown on plots fertilized with phosphates as an average for three years contained 0.378 per cent phosphorus compared to 0.336 for wheat from unfertilized ground. Such variations should not be of much significance in the nutrition of cattle on account of the relatively small portion of the ration coming from grains.

Quite different results are found from peat soils. Data taken by the Division of Soils, of the Minnesota Agricultural Experiment Station, indicate that on peat soils the fertilizers may exert a pronounced effect upon the mineral content of the grain. In 1918, oats grown on peat soil at the Golden Valley Peat Experiment Fields without fertilization contained 0.53 per cent phosphoric acid in dry matter. With phosphate

fertilizer this was increased to 0.84 and on burned peat soils to 1.15 per cent. Similar increases were found with barley, rye, and field peas.

It has been known since the work of Lawes and Gilbert and others many years ago that the mineral content of forages is subject to wide variations as the result of soil conditions. Ames and co-workers (2, 3) reported that variations in rainfall and the use of phosphate fertilizer directly affected the phosphate content of wheat straw and alfalfa. This work is supported by that of Forbes and others (9) with grasses. One of the most striking cases is reported by Price (41). Alfalfa from an untreated plot contained 0.56 per cent of calcium and 0.054 of phosphorus compared to 2.98 per cent of calcium and 0.179 of phosphorus from a plot to which limestone had been applied at the rate of two tons per acre.

An increase of about 50 per cent in the phosphoric acid content of clover-timothy hay on mineral soils was obtained by the Division of Soils, Minnesota Experiment Station, even where the hay from the untreated soils was equal to the average in phosphorus content.

A large amount of additional unpublished data taken by the same division show similar results on both mineral and peat soils. On peat soils in one experimental field the phosphoric acid content of the dry matter in oat straw was increased from 0.215 to 0.440 per cent by phosphate fertilizer. In buckwheat straw the average increase for three plots was from 0.09 per cent in unfertilized plots to 0.85 per cent where phosphorus was used.

Kellner (30), Stohmann (45), Theiler (46, 47), Tuff (48), and others noted that outbreaks of osteomalacia occur chiefly in areas of impoverished or naturally unproductive soils and following drouth. It has also been long known that the mineral content of hay may be depleted through leaching by rain (33).

The close relation observed between mineral deficiency troubles and deficient rainfall may involve several factors. One of these apparently is a lowered mineral content of the forage as the result of the reduced flow of water through the plant. Kellner (30) pointed out that both hay and straw were low in phosphoric acid following the dry season of 1893. Forbes and associates (9), experimenting with oats in pot cultures and grasses grown with and without irrigation, secured the same results.

Green Feed and Ultra-Violet Light as Possible Factors

The seasonal evidence of mineral deficiency troubles has been reported by practically all observers. Kellner (30), Theiler (46, 47), Tuff (48), and Henry (24) all state that the trouble is most severe after periods of drouth or, especially, following the winter season of feeding with dry forage. German investigators noted that cattle would thrive

on green grass from certain fields altho the hay from the same field would cause deficiency troubles when fed in the winter. They suggested that in the curing process some factor is lost which is indispensable for the utilization of the feed by the animal. These investigators also reported that the nature of the drying to which the hay has been subjected is a factor. Hay dried quickly in bright sun was said to give much better results than hay dried slowly in cloudy weather. It has been established by the investigations of Hart (19, 21), Hunt (25, 26), and Miller, Brandt, and Jones (37), that cattle utilize calcium and phosphorus more efficiently when the ration contains fresh green plant tissue such as millet, kale, or lawn grass. These investigators believe that the effect of green plant tissues is due to the presence of antirachitic vitamin which is less active in dry hay. A recent report by Steenbock and co-workers (44) shows that hay cured in the bright sunshine, presumably as a result of the exposure to ultra-violet light, retains more of both calcium and phosphorus than the same hay cured out of the sunlight. The facts established by these investigators offer a reasonable explanation for the close relation observed between drouth and mineral deficiency troubles and the seasonal occurrence of the disease which is usually noted.

The possibility that ultra-violet light is a factor in the seasonal incidence should also be given consideration. It is fully established that exposure of the animal body to ultra-violet rays, either from the sun or from a suitable quartz lamp, results in greater utilization of calcium and phosphorus. No attempt will be made to review the extensive literature of this subject. The investigations by Hart, Steenbock, and associates (22) concerning the effect of ultra-violet light on lactating goats and cows should receive special attention. It is also worthy of note that according to Dorno (6), sunlight in the northern hemisphere is lowest in ultra-violet rays from December to March. The usual period of most severe depraved appetite is near the close of the winter season, from February to May.

Yield of Milk and Composition of Milk Ash

It has long been observed in the extremely mineral deficient areas of Europe and Africa that the heavily milking cows are the first affected and that milk yields are reduced markedly when outbreaks of osteomalacia occur. Tuff (48) noted this condition especially in parts of Norway. If a mineral supplement such as bonemeal or herring meal was fed, the yield of milk was increased. With cows on pasture where osteomalacia did not occur, the milk yield was satisfactory even without such supplements. Theiler (46, 47) observed that ten cows receiving a ration otherwise very deficient in phosphorus produced 40 per cent more milk when the ration was supplemented with bonemeal than did a similar group of cows without bonemeal.

Meigs and Woodward (35) supplemented the rations of dry cows with sodium phosphate. On comparing the milk yield between the 10th and 40th days of the subsequent lactation with those of the previous lactation, they noted a 37.9 per cent increase over the expected quantity. They also found that the decline in milk production was less rapid on a high calcium ration without mineral supplement.

A number of investigations are also reported dealing with the relation of the mineral content of the ration to the ash of milk. Investigations reported before 1900 are somewhat conflicting. The positive results noted followed the feeding of large quantities of mineral supplements. Later experiments are uniformly negative, including the results reported by Golding and Paine (13), Jordan and associates (28), and others. Grimmer (11) concludes from a review of the literature that, "In general it may be said the feeding exerts no essential influence upon the composition of the milk ash so far as healthy animals are concerned. There is little possibility of producing milk rich in certain constituents, for example iron for anemia."

Most of these investigations either covered short periods or were made with cows presumably in normal condition at the beginning of the feeding period. In view of the present knowledge concerning the extent to which a cow will store mineral matter in time of ample supply and draw upon it in times of deficiency, experiments made under such conditions can hardly be looked upon as conclusive. Only in the report of the experiments by Jordan is there any evidence that the cows used were suffering from mineral deficiency to the extent of showing typical symptoms.

Magnesium Sulfate as a Possible Factor

Ibele (27) and Konig and Karst (31) concluded that a high sulfate content in roughages interferes with calcium utilization by cattle when the ration is somewhat low in this element. The physiological evidence for a harmful effect of the sulfate radical rests upon its limited utilization and the necessity of neutralizing any excess which is ingested or formed in metabolism. Ammonia secured from deamination of protein is commonly used for neutralizing the SO_4 radical, but theoretically the more useful bases such as Ca, Na, or K can be used also. The variety of elements available for the sulfate neutralization is thus seen to limit greatly the conditions under which an excess of sulfate would be expected to interfere with calcium utilization.

There is also a prevailing belief that an excess of magnesium may lead to disastrous results. The evidence in support of this is not definite. Magnesium sulfate is known to have an anesthetic effect when injected, which is counteracted by calcium chloride. Other evidence of a more nutritional character is that of Malcolm (34) that the in-

gestion of $MgCl_2$ hinders calcium deposition in young animals; and the experience of Hart and Steenbock (23) that $MgSO_4$ increased the urinary excretion of calcium in a pig, changing a slight retention of lime to a negative balance. It is clear, however, that the conditions under which magnesium is harmful require more careful delimitation, since Hart and Steenbock found that the feeding of potassium phosphate overcame the effect of magnesium on calcium balance; and Hart and associates (17) have stated that the addition of a large amount of magnesium salts to a corn ration did not prevent the production of normal offspring by cattle.

EXPERIMENTAL

A Survey of Affected Regions

A field survey was made of conditions in the regions affected in Minnesota preliminary to the preparation of a plan for experimental work. In September, 1923, thirty farms were visited in the area from which the greatest number of complaints had been received. These farms were not selected but all on certain roads were included. On every one, depraved appetite had been observed. In August, 1924, ten counties were visited from which numerous reports of trouble had been received. One locality where especially severe cases were found is 130 miles from the first locality studied. Several other less extensive trips were made to examine particular cows or for the purpose of buying animals and feeds for experimental purposes. By these means information was secured by personal visit from nearly a hundred farmers. When making these visits full information was obtained from the farmer as to his experience, and samples of hay, grain, and water were taken. A total of 69 samples of hay and 39 samples of water were brought to the experiment station for analysis. Soil samples were also taken, to be analyzed if it appeared desirable. In addition, information has been received by correspondence over a period of several years from more than a hundred additional farmers.

The most common symptom reported is depraved appetite, which is often exhibited in an extreme form. The owner usually first notices a desire on the part of his cattle to chew bones, later the animals gnaw wood, often to such an extent that the mangers in the barn have to be replaced in the spring. Fence posts of soft woods are almost devoured. Animals chew leather and eat dirt. Losses are not uncommon from animals attempting to swallow such material as slate or small rocks. Next to abnormal appetite the most marked symptom is stiffness of the joints; often so severe that the animal walks with great difficulty. Broken bones are sometimes observed but are by no means common. Owners state that affected animals lose their appetite, decline in weight, and shrink in milk. Testimony is uniformly to the

effect that heavily milking cows and growing animals are affected most severely. Bulls and dry cows, having little more than the requirements of maintenance to meet, are affected less severely, or may show no visible symptoms of mineral shortage. Cows affected while in milk tend to recover during the dry period. Considerable trouble was reported with breeding, but no more than the usual amount of abortion seemed in evidence. On many farms a cow is not expected to produce a calf more than once in two years. Heifers sometimes do not show oestrus until they are past two years old. The average calf crop in the worst affected district, as observed following a dry season, was estimated at less than 50 per cent of the normal. The trouble is reported as occurring more severely during the late winter and early

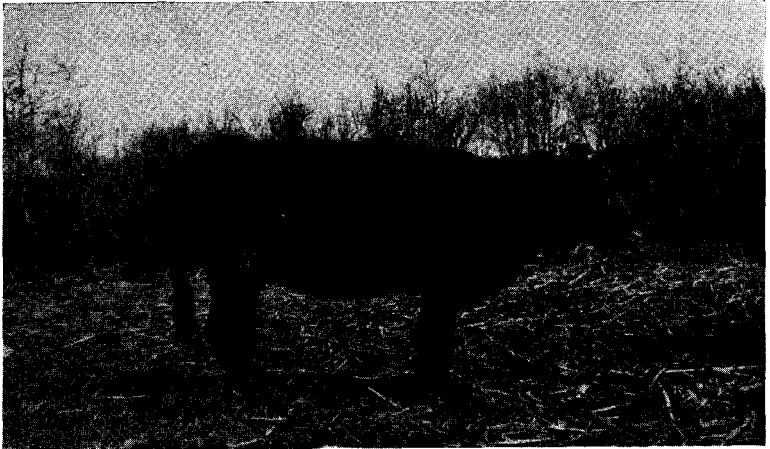


Fig. 1. Results of Mineral Deficiency

This cow was photographed on a farm in spring. She was suffering severely from the lack of minerals in her ration. She was so stiff she could scarcely walk, her joints made a noise as she moved, and she showed the typical abnormal appetite for two years at least. She recovered on pasture during the summer and the following winter received a bonemeal supplement. As a result she came through the winter with no sign of deficiency.

spring, especially following dry seasons. Figure 1 shows a typically severe case. The cattle usually recover during the pasture season and are as a rule about normal again by fall. Mature cows brought into the affected area from regions where the trouble is not prevalent do not exhibit the abnormal appetite until they have lived in the district at least a year. These troubles do not appear to be of recent origin, as older settlers observed similar conditions more than a quarter of a century ago. Many farmers in the newly settled parts of the affected area point to wild hay as the source of the trouble. Many of them depend largely upon wild hay, straw, and corn stover as feed for their cattle during the winter. Some of the affected herds receive little or

no grain. The information secured indicated that less trouble was experienced when legume hay was fed in place of the more commonly used prairie hay, but the use of home-grown alfalfa by no means insured freedom from the trouble. In fact, one herd showing especially severe symptoms, including broken bones, received alfalfa hay regularly.

Cattle were observed by the authors on some farms that showed decided symptoms after having been on pasture all summer. Visits made in the spring indicated that the description of conditions as given by cattle owners was by no means overdrawn. Figure 2 is an especially bad case, as seen in the spring. In one case investigated some members of a dairy herd had died from broken bones. One cow, unable to get up, was killed by the station veterinarian and found to have a broken pelvic arch. A few cases of crooked legs were observed; also some animals in which movement of the joints was accompanied by noise which could be heard distinctly at a distance of 20 feet. The sound suggested the rubbing together of two rough surfaces. Similar reports have been made of affected animals in other parts of the world, as mentioned in the review of literature.



Fig. 2. A Cow in Advanced Stages of Mineral Deficiency

This five-year-old cow on a farm in the affected area showed the characteristic stiffness and poor physical condition, and had exhibited the usual depraved appetite most of her life. She was slaughtered and the bones were taken for examination. She had freshened twelve months before and was not again pregnant. Her ribs were so soft a knife blade could easily be pushed through them.

Cattle grown in these areas are decidedly stunted in size and when mature their head appears too large for the body. Animals four years of age; on some farms, weigh less than 600 pounds as compared to a normal of 1000 to 1100 pounds for animals of similar age and breeding. It was also observed that cattle on farms where the trouble prevails at

times were listless and not inclined to move about, even tho no positive symptoms of mineral deficiency were noticed. It was evident from conditions as seen on the farms that serious financial losses are experienced through lack of proper growth, depreciated value of the carcass due to poor fattening, lower milk yields, and a poor calf crop. The trouble is especially detrimental to the dairy cow, but interferes with the production of cattle for meat as well. Representatives of the livestock market at South St. Paul are responsible for the statement that the quality of cattle coming to market from the counties where this trouble was studied is especially inferior.

Legumes grow luxuriantly throughout the affected area without requiring applications of lime, indicating that the soil has an adequate supply of available calcium. Sugar beets on this soil responded with increased yields to the applications of phosphate fertilizers.

It was reported that applications of phosphate fertilizer to the cultivated fields of one farm resulted in the cattle being less affected with depraved appetite. In another badly affected herd, additions of acid phosphate fertilizer to the grain ration overcame a serious outbreak of mineral deficiency in the herd. Several cows had died on this and neighboring farms in the spring of 1923 as the result of the deficiency.

Drinking water throughout the regions was found without exception to contain relatively large amounts of magnesium sulfate.

The boundary dividing affected areas from unaffected is in some places so sharply defined that the use of feed grown on one part of the farm may cause trouble while that from another part may be used without any bad results being apparent. Two farms were found in the unaffected soil area where the cattle had identical feeding conditions throughout the summer but in the winter one herd received hay grown on the farm (unaffected soil) while the second herd was fed upland prairie hay grown on the affected glacial prairie lands a few miles away. In April, cows in the first herd were in good condition while those in the second showed a strong craving manifested by chewing boards and bones.

Several herds were seen in which, as the result of advice previously received from the experiment station, bonemeal had been fed to cattle affected with mineral deficiency. Only two instances were reported in which bonemeal was said not to overcome the deficiency. Investigation of both cases showed that too little bonemeal had been used upon which to base any conclusions.

Some material was gathered regarding the relation of the mineral deficiency to the bones of cattle. A number of cases were seen or reported in which the pelvic bones of mineral deficient cattle were broken, with no apparent cause.

In the affected area, a five-year-old cow in an advanced stage of mineral deficiency was purchased. The animal had been fed cornstalks, mixed oat and wheat straw, and no grain during the previous winter. In the summer she was on lowland native grass pasture. The animal had been in milk thirteen months in her first lactation, was stiff, thin, and showed a decided lack of animation. Postmortem examination showed that the cow was neither pregnant nor ovulating. No corpus luteum or maturing ovum was present. No abnormal conditions of the abdominal and thoracic organs were noted. Two ribs and the rear cannon bones were dissected out. In securing these bones, it was found possible to cut directly through the costal cartilage, and to stick the knife well into any of the ribs. A pastern bone broke rather than allow the ligament to tear loose. The proximal end of a rib broke while being pried to free it from the vertebral attachment. While trimming off flesh, one of the ribs was cut before the damage was noticed. These bones were both soft and fragile. There was apparently a slight enlargement of the ribs at the costochondral junctions, but the condition was not sufficiently marked to be called "beaded." X-ray photographs showed the structure of the ribs to be much more open and coarse than in those taken from two experimental animals less affected.

The Region Where Mineral Deficiency Occurs

Reports have been received indicating mineral deficiency trouble in 32 counties in Minnesota. From scattering inquiries it also appears that the same troubles are experienced beyond the boundaries of the state and adjacent to the areas studied in Minnesota. The soil is of glacial origin, described by the Minnesota Geological Survey (32) as Young Gray Drift, and was originally practically all prairie. The exact extent of the area where trouble may occur has not been determined and for this reason no attempt is made to indicate the location by map. It does not appear to extend into the Red River Valley proper but is most marked just east of the limits of glacial Lake Agassiz.

Dr. F. J. Alway describes the soil conditions in the part of the state where the trouble occurs as follows: "In about one-third of the State of Minnesota—the western and southwestern prairie portions—phosphate-hunger of the soils is very common and widespread and from our field experiments it appears that on at least one-third of the fields acid phosphate or treble superphosphate can be profitably used on those crops most responsive to the fertilizer—alfalfa and the clovers." Figure 3 illustrates the results of applying phosphate fertilizer to soils in this part of Minnesota.



Fig. 3. Effect of Phosphate upon Wheat on a Renville County Farm in 1921. Each bundle was from six square yards. Fertilized on right. (Photo by Division of Soils.)

Varieties of Grasses in the Prairie Hay Used

The varieties of grasses characteristic of the upland and midland prairie hays were identified by F. H. Steinmetz, of the Division of Agronomy. Four chief grasses typical of the midland and lowland prairie hay, are:

- | | |
|--------------------------------|------------------------|
| <i>Spartina michauxiana</i> | (English slough grass) |
| <i>Calamagrostis inexpansa</i> | (Canadian blue joint) |
| <i>Phragmites communis</i> | (reed grass). |
- Sedges, which include several kinds of fine wire grasses.

Four grasses predominating in the upland prairie hay, are:

- | | |
|-------------------------------|-----------------------|
| <i>Andropogon furcatus</i> | (big blue stem) |
| <i>Sorghastrum nutans</i> | (Indian grass) |
| <i>Agropyron richardsonii</i> | (bearded wheat grass) |
| <i>Agropyron tenerum</i> | (slender wheat grass) |

The hay used in Experiment II was largely of the upland grasses, while that of Experiment III was more largely of the midland type. Since pure stands of grasses do not occur in this area, there was necessarily some mixing together of the two classes in the four carloads of hay used in the two experiments.

Analysis of Feeds Grown in Affected Regions

Oats is the grain crop most widely grown and fed in the areas studied. Samples of oats were taken in the course of the first survey from a number of farms where trouble was regularly experienced.

The oats used in the first experimental feeding trial was also purchased from a farm where the trouble was common. The analyses of these samples (Table V) indicated nothing abnormal regarding the mineral composition. This result was entirely in line with the conclusions of others, that the mineral composition of seeds and grains is not subject to much variation. The magnesium determination was included in the analyses of the hay samples on account of the possibility of this being a factor in the situation. The hay samples were taken during the survey and divided into two groups, "affected" and "unaffected," based upon the information received from the operation of the farm. It is fully appreciated that this is not necessarily an accurate division, as better feeding practices on some farms undoubtedly were responsible for placing them in the "unaffected" class, altho under different conditions of management they would have been placed in the other group. All the samples were taken in communities reporting trouble, and it should be clearly understood that the samples designated as "unaffected" do not include any samples from localities where the deficiency trouble is unknown.

Table I, which is a summary of these analyses, does not suggest a calcium deficiency. The magnesium appears slightly higher than average figures for the affected regions, the phosphorus is somewhat below average and is distinctly lower in the averages of samples from the affected regions. The individual analyses included in the average show some much more striking figures. Some of these figures, especially for the prairie hay, are extremely low in phosphorus, ranking in this element below the figures given by Theiler.

TABLE I
MINERAL COMPOSITION OF HAY FROM MINERAL DEFICIENT AREAS
Affected and Unaffected Farms

	No. of samples	CaO	P ₂ O ₅	MgO
		Per cent	Per cent	Per cent
Alfalfa hay				
Affected	14	2.646	0.434	0.709
Unaffected	9	2.459	0.588	0.655
Average (H. & M.)*		1.950	0.540	0.590
Prairie hay				
Affected	30	0.578	0.229	0.355
Unaffected	10	0.672	0.248	0.513
Timothy				
Affected	4	0.550	0.245	0.322
Unaffected	1	0.570	0.310	0.350
Average (H. & M.)*		0.250	0.310	0.170

* Henry and Morrison, Feeds and Feeding, 18th Ed., p. 752.

Some effect of the rainfall is evident from Table II. The difference in pasturing conditions in the two years was much greater than the figures for rainfall suggest. During the winter following the short

pasture season of 1923, unusually severe conditions of depraved appetite were reported; while following the better season of 1924, the reports of trouble were far less frequent.

TABLE II
RELATION OF RAINFALL TO MINERAL CONTENT OF FORAGE

	Rainfall	No. of samples	CaO	P ₂ O ₅	MgO
	Inches		Per cent	Per cent	Per cent
Alfalfa, 1923.....	17.49	7	2.576	0.456	0.793
1924.....	21.98	16	2.634	0.511	0.651
Prairie, 1923.....	17.49	16	0.570	0.173	0.377
1924.....	21.98	24	0.618	0.275	0.408
Timothy, 1923.....	17.49	3	0.623	0.250	0.380
1924.....	21.98	2	0.450	0.270	0.250

It is to be regretted that a more direct correlation can not be made between analyses of hay and severity of the mineral deficiency troubles reported for the same farm. So many conditions are involved that the exact relations can not be determined. It is by no means certain that one or even a limited number of samples fairly represent the hay used. The amount of grain fed, the amount of milk produced by the cows, and the personal equation of the man reporting his conditions are important factors to be considered.

Analysis of Water Samples From Affected Regions

The 38 samples of water were taken from the water supply used for the livestock on farms visited in the course of one of the surveys. The analyses are reported in Table III. Those designated as "affected" are from farms where definite symptoms of mineral deficiency had been observed in the cattle, those under the term "unaffected" are samples from farms in the same neighborhoods but not reporting symptoms of osteomalacia.

TABLE III
ANALYSIS OF WATER FROM FARMS IN THE REGION WHERE MINERAL DEFICIENCY
OCCURS IN CATTLE
Analysis in parts per million

Source	No. of samples	Ca	Mg	SO ₄	Ca-Mg ratio
Unaffected farms	12	22	37	109	1:1.7
Affected farms	26	21	46	220	1:2.2
Affected farms*	25	178

* Omitting one extreme sample.

The striking fact shown by these figures is the high sulfate content of the water supply, a large proportion of which is magnesium sulfate. Altho the larger amount appears from the affected farms, the difference is not striking when the one extreme sample is omitted. In addition to the samples reported, others mounting into the hundreds have been received by the Division of Agricultural Biochemistry from regions in

the state where the mineral deficiency troubles with cattle occur. Many of these were received as the result of correspondence regarding the troubles with cattle, others with requests for information as to the suitability of the water for household use. Water from this part of the state has a uniformly high sulfate content. Many wells supply water containing so much magnesium sulfate that a distinctly bitter taste is readily detected. Table IV gives data taken by the United States Geological Survey (published (32) and unpublished data). The first three counties are in the region where the mineral deficiency occurs and the last is in the southeastern part of the state where these troubles are unknown. The high magnesium and sulfate content is at once apparent.

TABLE IV
MAGNESIUM, SULFATE, AND TOTAL SOLIDS IN FARM WELL WATERS IN AFFECTED AND UNAFFECTED REGIONS

	Total solids, parts per million	Magnesium, parts per million	Sulfate, part per million
Big Stone County			
9 wells (affected region).....	1646	113	873
Lincoln County			
9 wells (affected region).....	1264	67	543
Mahnomon, Norman, and Ottertail Counties			
13 wells (affected region).....	599	42	133
Rice County			
18 wells (unaffected region).....	521	33	40

Plan of Experimental Work

The information gathered during the earlier surveys was used in planning experiments designed to furnish more definite information as to the cause of the trouble.

In planning the experimental work the urgent call for information as to the prevention of osteomalacia led to our attention being directed first of all to the possibility of alleviating the trouble by means of bone-meal. Later, attention was directed to a determination of the nature of the deficiency and the possible significance of other factors. The investigations conducted during 1923, 1924, and 1925 represent three distinct experiments.

Experiment I.—The efficiency of bonemeal as a cure and as a preventive of depraved appetite was tested by means of a co-operative feeding experiment. Six typically affected herds in the mineral deficient area were used in this trial.

Experiment II.—This experiment, conducted at the experiment station, was to determine if depraved appetite could be produced among cattle from the affected regions but not at the time showing symptoms, by the use of feed grown on farms where trouble regularly occurred during the winter season.

Experiment III.—After positive results were obtained from the animals used in the previous experiments, mineral supplements were added to the basal ration. The effect of the same mineral supplements was determined on other cattle from the affected area which exhibited extreme but typical symptoms of mineral deficiency. The extent to which magnesium sulfate may be a factor in causing depraved appetite was studied in a limited way. Work on this phase of the problem is still in progress.

Composition of Feed and Water Used in Experiments II and III

Prairie hay and oats were selected for the basal ration as representing the common feeding practice of the locality where the most severe symptoms of mineral deficiency were found. All prairie hay used was grown on farms where this trouble is common. In November, 1923, at the time of purchasing the cows which were used in Experiment II, a carload of prairie hay and a carload of oats were purchased which were grown on farms where mineral deficiency trouble had been prevalent the previous year. A second carload of the same hay was purchased in the winter of 1924. In the fall of 1924 samples of hay were secured from seven farms where trouble had occurred in the past, for analysis preliminary to purchase. When the results were available, the hay was selected which showed a typical low phosphorus content, which the first experiments had indicated as associated with the trouble under investigation.

The analyses given in Table V show nothing abnormal in the mineral composition of the oats. This corroborates the results of others, as cited in the review of literature, that the mineral composition of grains and seeds is little influenced by the soil on which they grow. In view of these results it appeared unnecessary to go to the extra expense and trouble of securing oats from affected farms. Market oats were therefore used in subsequent experiments. The water used throughout the experimental work was the tap water from the University water supply, the source of which is at times the St. Paul public supply and again the well on the Agricultural College grounds. The analysis of water from the two sources is as follows:

	Parts per million					Total solids
	Ca	Mg	Na-K	HCO ₃	SO ₄	
Public supply	48	19	12	305	Tr.	224
Agricultural college	44	24	18	291	Tr.	250

In Experiment II magnesium sulfate was added to the water consumed by the cows at the rate of 16.47 grams per hundredweight. This amount was chosen as representative of a composite sample of waters from the locality from which the cattle came.

TABLE V
MINERAL COMPOSITION OF HAY AND OATS USED

Feed	Date fed	Moisture	CaO	P ₂ O ₅	MgO
		Per cent	Per cent	Per cent	Per cent
Prairie hay, Lot 1.....	11-'23 to 5/23-'24	8.82	0.80	0.20	0.35
Prairie hay, Lot 2.....	5/23-'24 to 12/6-'24	9.33	0.73	0.25	0.48
Prairie hay, Lot 3.....	12/6-'24 to end	8.62	0.46	0.17	0.31
Oats, Lot 1.....	11-'23 to 12/6-'24	7.20	0.19	0.80	0.27

Experiment I. Prevention of Depraved Apptite Through Feeding Bonemeal

Six herds of cattle (119 animals) known to have suffered from depraved appetite for several years, were selected in November, 1923, for use in a co-operative feeding experiment in the affected district. Five hundred pounds of bonemeal of the grade known commercially as "raw bonemeal" was supplied for use in each herd. This is the same product used for poultry except that for cattle it is finely ground. This packing house product is said to be made from the skulls of cattle that have passed government inspection. The material is subjected to the action of steam for several hours, which removes danger of disease organisms. Each co-operator was instructed to allow his herd free access to the bonemeal by keeping it available in a box in the yard. Feeding of the bonemeal was started at the beginning of winter. From previous experience, symptoms of mineral deficiency would be expected to appear toward the end of winter.

At first relatively large amounts of bonemeal were consumed, but as the winter passed the cattle ate somewhat smaller quantities. One co-operator continually mixed salt with the bonemeal. His cattle consumed much larger amounts of bonemeal than the other herds, probably in order to get the salt. Had the bonemeal and salt been fed in separate containers, undoubtedly this herd would have used less bonemeal. However, no ill effects were noted from the greater consumption of the bonemeal. The amounts used are given in Table VI.

TABLE VI
BONEMEAL CONSUMED IN THE CO-OPERATIVE FEEDING EXPERIMENT

Herd	Feeding began	Herd inspected	Bonemeal consumed	No. of cattle fed	Bonemeal per animal in 30 days
			Lbs.		Lbs.
A	12/ 5-'23	4/29-'24	300	32	1.92
B	12/ 1-'23	4/26-'24	400	26	3.12
C	12/10-'23	4/26-'24	350	19	3.98
D	11/16-'23	4/29-'24	400	14	5.16
E	11/16-'23	4/27-'24	450	15	5.49
F	12/10-'23	4/27-'24	500	13	8.24

One hundred nineteen cattle were fed 150 days, and consumed an average of 4.05 pounds of bonemeal each per month. Excluding herd F, for which salt was mixed with the bonemeal, 106 cattle consumed

an average of 3.57 pounds of bonemeal each per month. The condition of the cattle had decidedly improved at the time of the final inspection in April, 1924. They appeared more thrifty and active, and were in fair flesh. No indications of depraved appetite appeared in any of the herds receiving the bonemeal. One year after this feeding test was completed, reports were received from the co-operators who had continued the feeding of bonemeal. No trouble occurred the second winter, altho depraved appetite was said to be prevalent in the locality, but in a less severe form than during the winter of 1923-24. One of the reports contained some significant observations, quoted as follows:

"In answering your letter . . . I wish to state that this depraved appetite of my own herd was not so bad. My neighbors are complaining of their cattle eating bones and boards. They are not feeding bonemeal.

"My cattle would not take to bonemeal very much. I fed beet tops all winter

"Of these last two winters (while feeding bonemeal), my cows get with calf much easier. Before this we had trouble. This depraved appetite is at its worst when we feed much wild hay."

Reports have also been received from others who fed bonemeal on recommendation of the experiment station and in every case the results were favorable. Similar results are also reported to follow the feeding of certain commercial mineral mixtures and phosphate fertilizer.

Experiment II. Production of Depraved Appetite Under Controlled Conditions

The purpose of this experiment was to determine if depraved appetite could be produced under controlled conditions. Six cows from 2 to 7 years old were brought to the experiment station in November, 1923, from a locality where depraved appetite is especially severe. They came from farms where trouble had occurred in previous years, and also in the winter and spring of the same year. The cows were in an unthrifty condition but were not at the time showing symptoms of bone chewing. This is in accordance with the usual experience that the symptoms largely if not entirely disappear during the pasturing season. With one exception these animals had shown typical symptoms the previous winter.

The object in selecting cows from affected farms was to start with animals that would be expected to show symptoms if retained on the farm and fed home-grown feeds. A carload of prairie hay and a carload of oats were purchased that were grown on farms where the trouble had been prevalent the previous year. With the possibility in mind of the high magnesium sulfate content being a factor, the plan was adopted

of adding this sulfate to the drinking water consumed by the animals during the course of the experiment.

The basal ration consisted of upland prairie hay, ground oats, common salt, and the water modified through additions of magnesium sulfate as described above. Mineral supplements, when used, were mixed into the grain ration daily. Mono-basic sodium phosphate was fed at the rate of 100 grams and calcium carbonate at the rate of 150 grams daily. These amounts were purposely placed rather high to insure a margin above the requirements of the animal.

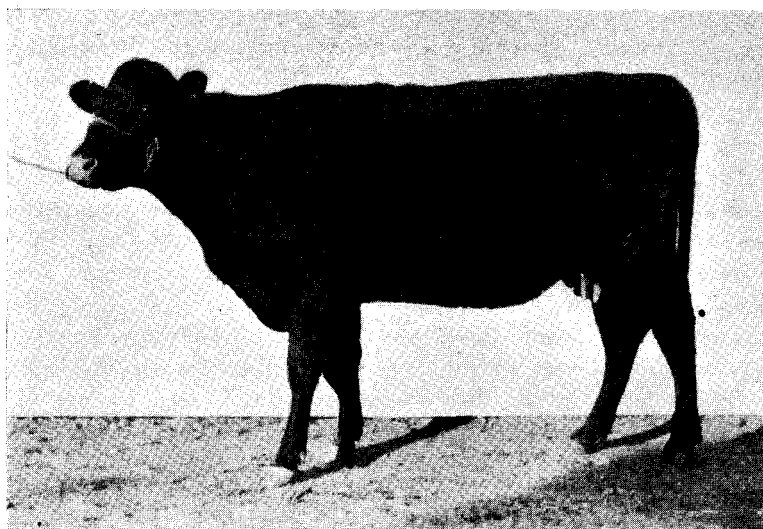


Fig. 4. E-32, When Brought to the Experiment Station

She was in good condition when placed on the basal ration, prairie hay and oats grown on affected farms. She was not raised on a farm having trouble, but was in such a locality when purchased. Altho showing no symptoms of mineral deficiency, it is probable her reserve was low.

The animals and rations used in Experiment II were as follows:

Animal	Age	Lactation	Ration
E-32	Mature	In milk	Basal ration
E-33	4 years	In milk	Basal ration
E-34	4 years	Dry	Basal ration plus NaH_2PO_4
E-35	Mature	In milk	Basal ration plus NaH_2PO_4
E-36	4 years	In milk	Basal ration plus CaCO_3
E-37	2 years	Not bred	Basal ration plus CaCO_3

The amount of prairie hay fed was governed by the amount each animal would consume without excessive waste. Ground oats was fed according to milk production, a minimum of 4 pounds daily being used. Animals were watered twice daily. Weighed amounts of salt were before each animal at all times. Each had a separate box-stall bedded with wood shavings. The herd was turned together into an open exercise lot during all favorable weather throughout the year. Complete feed and production records were kept. Five-day composite milk samples were taken monthly and preserved with formalin for mineral analyses. Body weights were secured on three consecutive days at the beginning and the close of each experimental period. Photographs were taken at intervals to show any points of interest in the progress of the experiment. Complete records were kept of the appearance of oestrus, and of breeding dates. The period covered by this experiment was ten months.

Depraved appetite developed with E-36 in 118 days, with E-32 in 186 days, and with E-33 in 194 days. E-34 and E-35, that received a phosphate supplement, failed to develop depraved appetites and improved in condition. E-37 also failed to show any abnormal appetite. The last three animals improved in condition and gained in body weight. In all six animals oestrus was delayed.

As depraved appetite developed in animals receiving calcium carbonate, it was surmised that the factor for utilization might be absent. Accordingly 50 cc. of cod liver oil was added daily for 34 days to the ration of E-36. No change could be observed in the abnormal appetite or the physical condition of the animal.

This experiment indicated that symptoms similar to those observed in the affected area, altho less severe, had been produced by the use of feeds from farms where the trouble was common. The cows used had previously shown symptoms on farms where the trouble was common but were not showing these symptoms when the experiment was begun. The fact that the symptoms observed in the experimental animals were less severe than those often experienced on farms where trouble occurs, is probably to be attributed to the more liberal feeding practiced. Note in Table VII that all animals were fed considerably above their requirements as estimated from a feeding standard. It also showed the significant fact that two animals receiving the supplement containing phosphorus not only did not show symptoms of the trouble but gained rapidly in condition during the ten months covered by the experiment. The fact should be kept in mind that all the animals received magnesium sulfate in their drinking water during the experimental period.



Fig. 5. E-32, After Nine Months on the Basal Ration

While on the basal ration she became thin in flesh altho her ration contained 50 per cent more digestible nutrients than needed according to the Morrison standard. She developed a craving for bones after several months on the basal ration.

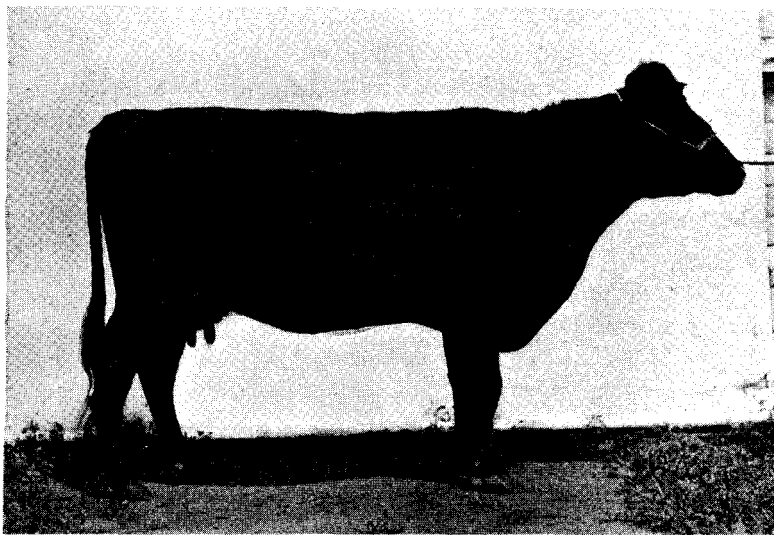


Fig. 6. E-32, Nine Months Later than Figure 5

During this time she received tricalcium phosphate as a supplement to the basal ration. With no increase or change in the feed received except the phosphorus supplement, she gained 293 pounds in 300 days.

TABLE VII
PLAN OF FEEDING MINERAL SUPPLEMENT, AND GAIN IN WEIGHT

Animal No.	Days included	Supplement to basal ration	Plane of nutrition*	Average daily gain	Average daily milk yield
			Per cent	Lb.	Lb.
E-32	285	None	144	-0.68	10.1
E-32	300	Ca ₃ (PO ₄) ₂	150	+0.98	19.3
E-33	285	None	134	+0.15	6.4
E-33	90	NaH ₂ PO ₄	132	+2.18	2.0
E-33	210	None	110	-0.16	10.8
E-36	334	CaCO ₃	134	+0.27	4.0
E-59	220	CaCO ₃	123	+0.27	6.9
E-37	360	CaCO ₃	167	+0.85	None
E-58	90	CaCO ₃	134	+0.41	3.8
E-58	210	NaH ₂ PO ₄	118	+0.51	4.6
E-34	246	NaH ₂ PO ₄	129	+0.64	Dry
E-35	280	NaH ₂ PO ₄	145	+0.63	4.8
E-35	300	NaH ₂ PO ₄ +MgSO ₄	132	No change	8.5
E-62	260	NaH ₂ PO ₄	118	+0.40	5.3
E-60	183	Ca ₃ (PO ₄) ₂	127	+0.79	2.4
E-61	260	Ca ₃ (PO ₄) ₂	149	+1.13	Dry

* Based upon the total digestible nutrients required according to Morrison's feeding standard.

Experiment III. Curing Affected Animals Through Additions of Single Mineral Supplements to the Basal Ration

In the third feeding experiment, an attempt was made to "cure" animals affected with depraved appetite, through additions of certain mineral supplements to the basal ration of prairie hay, ground oats, common salt, and water, without any additions of magnesium sulfate. E-32, E-33, and E-35 were retained from Experiment II. Five additional animals, all severely affected with depraved appetite at time of purchase, were secured for use in this experiment. All the experimental animals except E-35 showed the symptoms typical of mineral deficiency when placed on this experiment.

The mineral supplements used and the amount fed per animal per day were as follows:

Calcium carbonate	100 grams
Tricalcium phosphate	103 grams
Mono-basic sodium phosphate.....	128 grams
Magnesium sulfate	85 grams

The supplements were fed by mixing them with the grain ration daily. Methods of feeding, management, and record keeping were the same as in Experiment II. Dr. W. L. Boyd made ovarian examinations of all animals at regular intervals.

The experimental animals and rations used were as follows:

Animal	Age	Lactation	Bred	Mineral supplement
E-32	Mature	In milk	June 1, 1924	Ca ₃ (PO ₄) ₂
E-61	2 years	Dry	Open	Ca ₃ (PO ₄) ₂
E-33	Mature	In milk	June 21, 1924	NaH ₂ PO ₄
E-62	2 years	In milk	Open	NaH ₂ PO ₄
E-58	3½ years	In milk	Open	CaCO ₃
E-59	Mature	In milk	Open	CaCO ₃
E-35	Mature	In milk	June 11, 1924	NaH ₂ PO ₄ plus MgSO ₄
E-60	2 years	In milk	Open	Ca ₃ (PO ₄) ₂ plus MgSO ₄

E-32, E-33, E-60, E-61, and E-62 recovered rapidly from depraved appetite, and gained in either body weight or milk flow or both, on receiving the addition of either tricalcium phosphate or mono-basic sodium phosphate to the basal ration. E-35 showed no depraved appetite at the beginning of Experiment III, or even after 360 days of magnesium sulfate feeding. E-58 and E-59 made small gains in weight but appeared to decline rather than improve in vigor during the period when calcium carbonate was added to the basal ration. After 90 days of such feeding, E-58 became very weak. The calcium carbonate was then replaced by 100 grams of mono-basic sodium phosphate daily. The same substitution was made in the ration of E-59 after 190 days. Both animals made steady improvement after the phosphate supplement was added to the daily ration. It was observed that the appearance of oestrus was very much delayed with E-58, E-59, E-60, and E-61 while on experimental rations.

Effect of Adding Mineral Supplements

The primary purpose of the experiments reported was to determine the element lacking in the basal ration, and the conditions of feeding and the selection of cows in regard to lactation were based primarily upon this consideration. When brought to the experiment station the cows were far advanced in lactation, some were, in fact, practically dry, making it impossible to expect results of any consequence regarding increase in milk production from the addition of mineral supplements. The ration fed was in all cases above the requirements of the animals (measured by Morrison feeding standards²) in total digestible nutrients and always in protein, as well. The liberal feeding was to insure that the results obtained were not merely those of insufficient nutrients. That the quality of protein was not above criticism on account of only two plants being represented, is recognized. It is also fully appreciated that the relation of the mineral supplements to gain in weight and condition or to milk production could be obtained to better advantage if the conditions of the experiment were set up for that particular purpose.

² Feeds and Feeding, 18th Ed., p. 746.

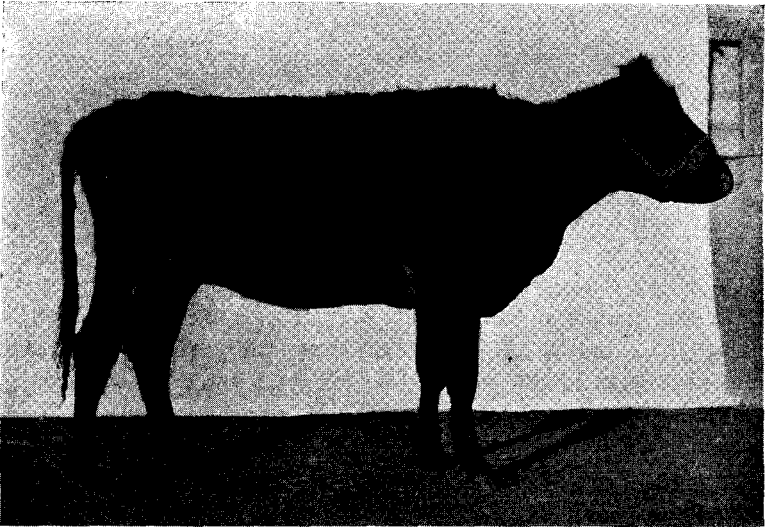


Fig. 7. E-33, When Brought to the Experiment Station in December

She showed the thin condition, undersize, and inanimation typical of cattle during the fall months on affected farms. She was not showing depraved appetite at the time.

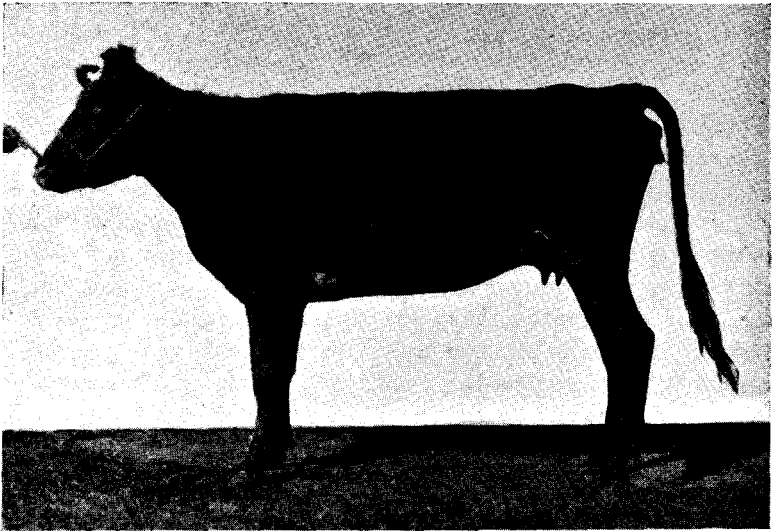


Fig. 8. E-33, After 281 Days on the Basal Ration

Her average gain was 0.15 pound daily on a feed intake of 34 per cent above requirements. She showed abnormal appetite after several months.

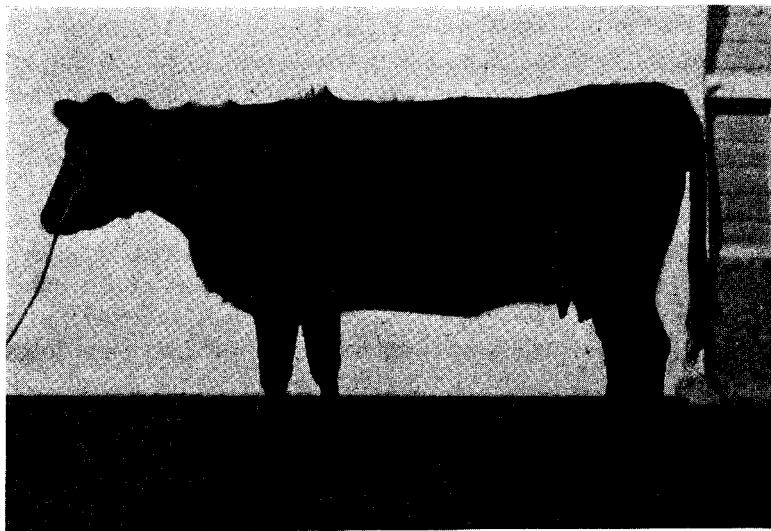


Fig. 9. E-33, After Receiving Sodium Phosphate in Her Ration for 90 Days
On a feed intake of 33 per cent above requirements her average gain was 2.18 pounds daily. The depraved appetite disappeared within six weeks.

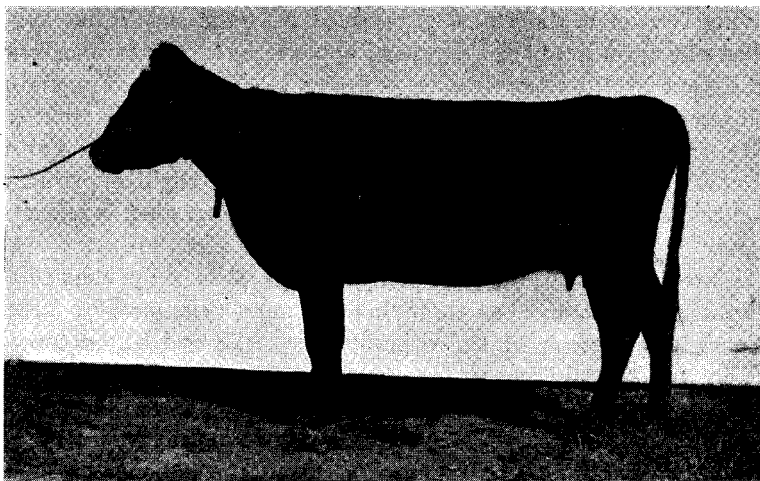


Fig. 10. E-33, After 210 Days on the Basal Ration

At the beginning of this period she was in condition shown in Fig. 9. On the ration supplying 10 per cent above her requirements she lost an average of 0.16 pound daily. Abnormal appetite had not again developed at the time of this photograph.

Table VII presents the data available in a form to bring out the relations between the ration and the gain in weight. The requirement of each animal for total digestible nutrients was calculated for each 30-day period, using the Morrison feeding standard. The requirements include the nutrients necessary for maintenance and for the milk produced, if any, but with no allowance for gain in weight. The total digestible nutrients supplied by the ration were calculated by using the tables from the same author. The results are given in the table as "percentage of total digestible nutrient requirement received," and serve to indicate in a concise manner the plane of nutrition of the animal. The amount of milk produced is also given, especially on account of the important relation of milk production to mineral deficiency and to gain in condition and weight of animals concerned. It is not intended that conclusions be drawn from these data regarding the relation of the mineral supplements to the yield of milk.

Two cows, E-32, E-33 (2 periods), received the basal ration alone. It will be noted in two out of the three cases that the animals lost in weight, while in the third the gain was only 0.15 pounds daily. Both E-32 and E-33 developed clearly marked cases of depraved appetite, the former in 186 days, the latter in 194 days. Both cows were producing some milk at the time. During the second period for E-33 on the basal ration she freshened on the 110th day. The tax of producing milk is undoubtedly responsible for her decline in weight, altho she was receiving feed at a plane of 110 per cent. At the end of the period she had not again developed depraved appetite. Her appearance under the different conditions of feeding is shown by Figures 7, 8, 9, and 10.

Three animals, E-36, E-59, and E-58, received the basal ration with calcium carbonate supplement for varying lengths of time. For the first month there was some reason to believe that a slight improvement in condition was noticeable in the way of a more alert appearance. However, E-36 showed the desire to chew bones after 118 days, which was before E-33 and E-32, receiving the basal ration only, showed this symptom. She continued to show this and other symptoms of mineral deficiency to the close of the experiment, at the end of 10 months. Thinking the vitamin factor for the utilization of calcium might be lacking, beginning with the ninth month this cow received 50 cc. of cod liver oil daily for 34 days with no apparent results. Her appearance at the beginning of the experiment and after receiving the supplement is shown by Figures 11 and 12. Both E-36 and E-59 made a gain of 0.27 pound per day during the period of calcium feeding. Considering the plane of feeding, 134 and 123 per cent, and the small milk yields, this gain appears rather small. E-58, according to the records, made a gain of 0.41 pound daily for 90 days. However, appearance

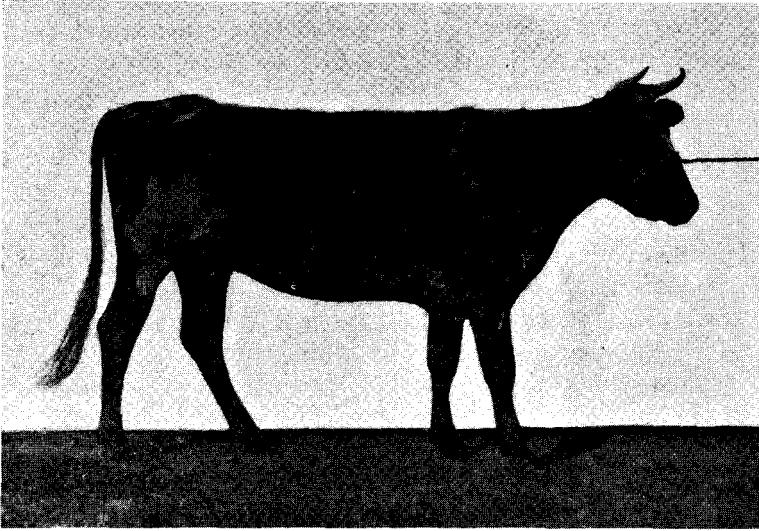


Fig. 11. E-36, When Received at the Experiment Station

She exhibited the typical conditions of cattle on the affected farms for the season (December). She was thin in flesh, stunted in size, in milk since spring and not pregnant, not showing depraved appetite.

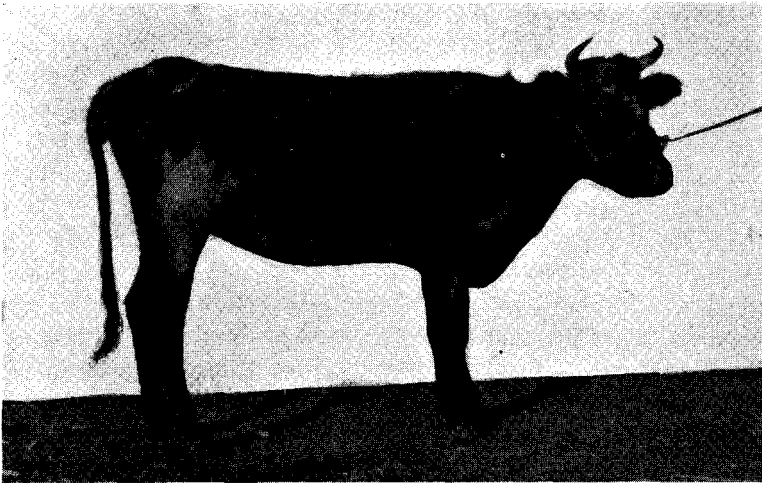


Fig. 12. E-36, After Receiving the Basal Ration and Calcium Carbonate for Nine Months

She gained 0.27 pound daily on a ration supplying 36 per cent more than her needs. Symptoms of depraved appetite developed during the winter and continued to the end of the experiment. First oestrus appeared in May after about a year in milk.

did not bear out this suggestion of improvement as the symptoms of mineral deficiency became more severe, and the ration was changed at the end of this period largely because it was feared the animal would no longer be able to get up. The heifer E-37 made a gain of 0.85 pound daily for a year. It should be noted that her feed intake in proportion to requirement was the highest of all, reaching 167 per cent as an average. It is probable that this heavy food intake resulted in a sufficient supply of phosphorus, as the cow never was in milk. No sign of oestrus was observed until a few days before the end of the year, and no symptoms of mineral deficiency developed.

Five animals in all received mono-basic sodium phosphate—E-58, E-33, E-34, E-35, and E-62. The feeding period of E-58, covering 210 days, gave outstanding results. This animal, as previously mentioned, in the beginning showed the most extreme symptoms of all animals used. She was extremely thin in flesh, weak, so stiff in the joints she could scarcely walk and movement was accompanied by noises in the joints audible for 20 feet. During the 210 days on the phosphate supplement, she made an average gain of 0.51 pound daily on a feed intake of 118 per cent. The acute symptoms disappeared in about six weeks, including the milder symptoms of a desire to chew bones. During this period her ovaries became normal, ovulation began, and she was bred May 28, becoming pregnant with the first service. Her condition at various stages is shown by Figures 13, 14, 15, and 16.

E-33 received the sodium phosphate for 90 days following a period on the basal ration. With a feed intake of 132 per cent she gained at the rate of 2.18 pounds daily. The fact that she was dry a portion of this time was undoubtedly a factor in the rapid gains. All symptoms of mineral deficiency, including desire to chew bones, disappeared.

E-34, as shown in Table VII, on a feed intake of 129 per cent plus the sodium phosphate, gained 0.64 pound daily for 246 days. The fact that she was dry and farrow was probably a factor in the rapid gains. No sign of mineral deficiency appeared.

E-35 was in poor condition when started, showing some leg weakness but no other symptoms. As a result of feeding 280 days at an intake of 145 per cent of requirements, she gained 0.63 pound daily and produced an average of 4.0 pounds of milk. She showed a striking improvement, becoming vigorous and alert in appearance within a few weeks. No symptoms of mineral deficiency were observed after those slightly in evidence at first had disappeared within the first 2 months.

E-62, an open heifer milking in her first lactation period, showed severe symptoms at the beginning of a 260-day period on sodium phosphate. During this time on a feed intake of 118 per cent and producing

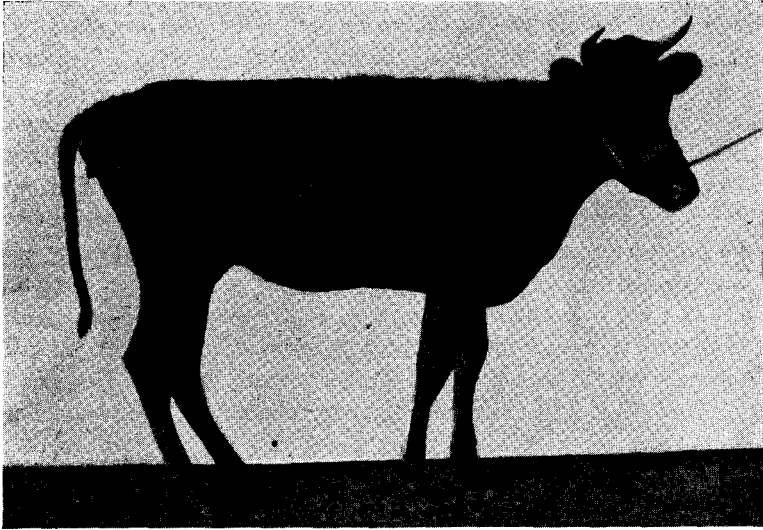


Fig. 13. E-58, When Received from a Badly Affected Farm

This animal had not recovered during the summer as is common, owing probably to dry weather limiting grass to low land. When received in September her condition was very bad. She could barely walk and movement of her joints could be heard for 20 feet. She had been in milk since spring and was open, her ovaries were not functioning.

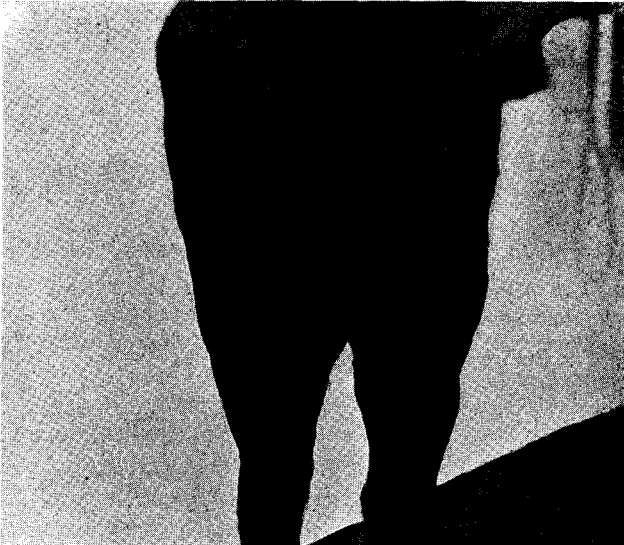


Fig. 14. Rear View of E-58 When Received
The weak condition of her hind legs is shown.

an average of 5.3 pounds of milk, she lost all symptoms of deficiency and gained an average of 0.40 pound daily. Her ovaries, which were abnormally small in the beginning, became normal, ovulation began and she was bred successfully.

Three animals, E-32, E-60, and E-61, received tri-calcium phosphate as a supplement, accompanied in case of E-60 by magnesium sulfate.

The most outstanding recovery in condition and gain in weight made among all the experimental animals was by E-32 when receiving tri-calcium phosphate. Altho calving during this period and milking liberally, she gained nearly a pound per day for 300 days as shown by Table VII (Fig. 6). All symptoms of depraved appetite disappeared shortly after the use of the phosphorus supplement was begun. The large gain in weight was undoubtedly due to the fact that she was fed on the plane of 150 per cent nutrient requirements. She cleaned nor-

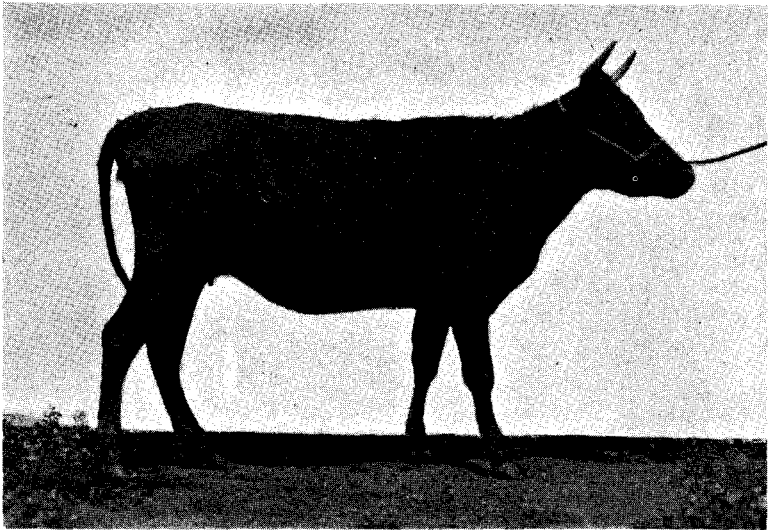


Fig. 15. E-58, After Seven Months on the Basal Ration Plus Sodium Phosphate

During this period she gained 0.51 pound daily with a feed intake of 18 per cent above requirements. Her abnormal symptoms disappeared in about six weeks. Her ovaries began to function in May after receiving the phosphorus five months.

mally after calving and showed oestrus in about three months. Figures 4, 5, and 6 show her condition when received, after receiving the basal ration, and later after receiving the supplement.

E-60, receiving the tri-calcium phosphate, made the excellent gain of 0.79 pound daily for the 183 days she was on the experiment. She showed severe symptoms of mineral deficiency at the beginning, includ-

ing stiffness and depraved appetite. These symptoms soon disappeared entirely. Her ovaries were not functioning when she was put into the experiment. She was slaughtered after 183 days on account of reacting to the tuberculin test. Her ovaries appeared normal altho she had not shown oestrus. The addition of the magnesium sulfate to her ration did not interfere with liberal gains in weight and prompt recovery from symptoms of mineral deficiency.

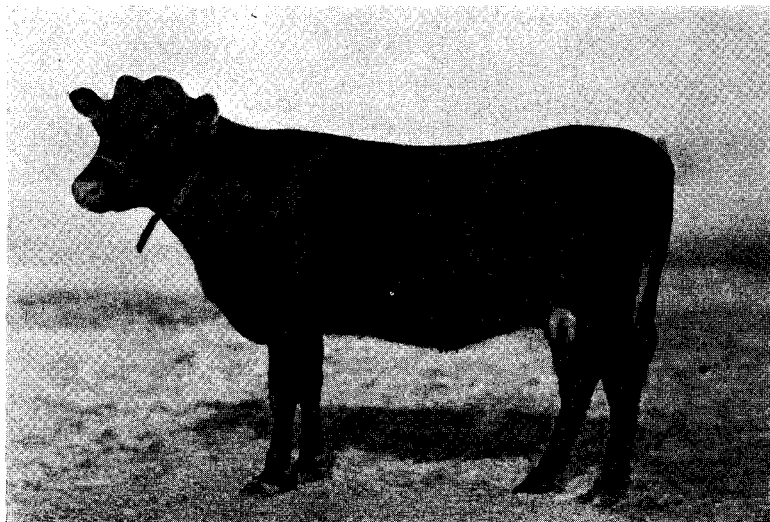


Fig. 16. E-58, After Receiving the Basal Ration and Phosphorus 13 Months

During this period she gained in weight from 498 to 860 pounds. She was dehorned to prevent injury to other animals.

E-61 also received tri-calcium phosphate for 260 days. Her gain in weight was 1.13 pounds per day with a feed intake of 149 per cent. The fact that she was dry made conditions favorable for gains. Her change in condition as the result of the supplement was very marked. In the beginning she exhibited, with one exception, the most severe symptoms of mineral deficiency of all the animals used. These symptoms all disappeared within a short time and before the end of the period the animal showed every indication of health. Figures 17 and 18 show her condition before and after the feeding of the phosphate supplement. She was open when received in November, 1924, and there was no indication that her ovaries were functioning. In May, 1925, she showed oestrus, was bred, and became pregnant.

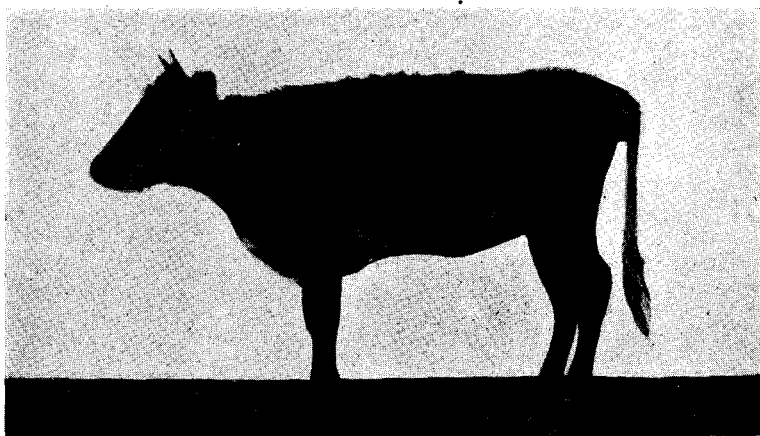


Fig. 17. E-61, When Received from the Same Herd and in Same Condition as E-58 (Fig. 13)
In milk from six to seven months, ovaries not functioning.

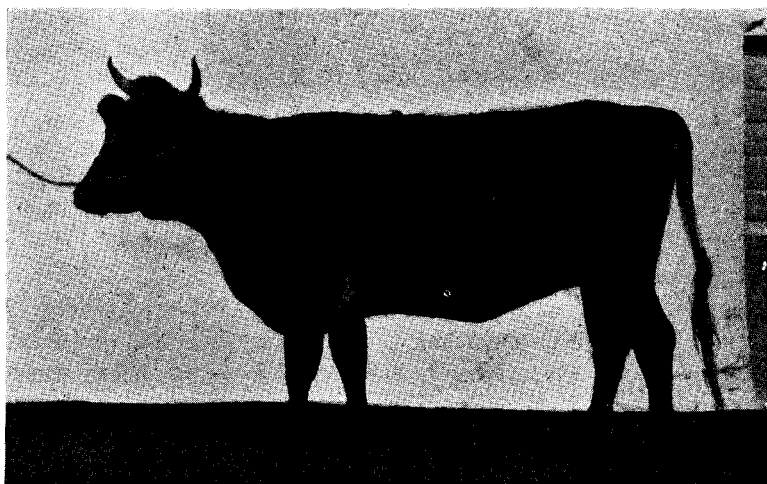


Fig. 18. E-61, After 300 Days on Basal Ration with Tri-Calcium Phosphate Supplement
She gained in weight from 475 to 808 pounds, an average of 1.11 pounds daily with a
feed intake of 49 per cent above requirements. The importance of phosphorus in making this
gain is seen by comparing Figures 5, 8, 12.

Effect of Extreme Mineral Deficiency on the Mineral Constituents of Milk

The experiments reported afforded opportunity to obtain data from cows showing extremely severe symptoms of mineral deficiency resulting from prolonged confinement to a mineral deficient diet. The data from four cows, given in Table VIII, show the composition of the milk when receiving the basal ration and again while receiving the mineral supplement. Each sample represents a five-day composite sample taken in the middle of a 30-day period. While some variations are noticeable in the calcium and phosphorus figures, the changes are not large enough to be significant and no relation can be detected to the character of the supplement fed. In Table IX analyses of the milk produced by cows on the basal ration and showing severe symptoms are arranged to show the relation to normal milk. The check sample is a composite representing the milk of 40 cows of four breeds in the University herd. The analyses were made at the same time as those from the experimental animals. These data show some indications of increase in milk production with phosphate supplements, altho the milk production of three of the animals used was so low in the beginning that the results are of no special significance. The comparisons bring forth no evidence that the ash constituents were affected by the extreme conditions of mineral deficiency from which the animals were suffering.

TABLE VIII
EFFECT OF MINERAL SUPPLEMENTS ON YIELD AND COMPOSITION OF MILK

Mineral supplement fed	No. of samples	Daily milk yield		Fat	Ash	P ₂ O ₅	CaO
		Lb.	Per cent				
Cow E-32							
Basal ration	4	16.96	13.31	3.51	0.717	0.236	0.172
Ca ₃ (PO ₄) ₂	3	20.01	12.87	4.21	0.736	0.193	0.143
Cow E-58							
Basal ration	1	3.94	16.74	...	0.875	0.260	0.210
CaCO ₃	2	4.30	15.21	4.43	0.730	0.190	0.160
NaH ₂ PO ₄	4	5.13	14.52	4.15	0.716	0.223	0.163
Cow E-59							
Basal ration	1	6.36	16.21	...	0.875	0.275	0.202
CaCO ₃	4	7.44	13.96	5.08	0.780	0.244	0.185
NaH ₂ PO ₄	1	6.98	13.99	5.04	0.780	0.246	0.182
Cow E-62							
Basal ration	2	5.68	14.53	4.87	0.785	0.235	0.182
NaH ₂ PO ₄	2	6.55	14.27	4.78	0.750	0.230	0.180

TABLE IX
CALCIUM AND PHOSPHORUS IN MILK FROM MINERAL DEFICIENT RATIIONS
COMPARED TO NORMAL

	No. of samples included	Total ash, per cent	P ₂ O ₅		CaO	
			Per cent	Per cent of total ash	Per cent	Per cent of total ash
Check sample	1	0.717	0.215	29.9	0.170	23.6
Cow E-32	4	0.717	0.235	32.6	0.172	23.9
Cow E-58	1	0.875	0.260	29.7	0.210	24.0
Cow E-59	1	0.875	0.275	30.8	0.202	23.0
Cow E-62	2	0.785	0.235	31.7	0.182	25.1

Observations on Reproduction

As indicated in the review of literature, considerable evidence is available indicating that a deficient mineral supply may be reflected by trouble with reproduction. In some studies the effect noted was the retarding of the oestrus period; in others, abortion. The field survey pointed decidedly toward a relation between the mineral deficiency trouble and reproduction. In some herds the calf crop was not over 50 per cent in the years following dry seasons.

Evidence of a relation of the mineral deficient diet to reproduction is found in the results of our experimental work. The cows used were examined at intervals by Dr. W. L. Boyd, of the Division of Veterinary Medicine. Ovarian examinations failed to disclose a single case of pregnancy among the cows showing severe symptoms at the time of purchase, altho all were from herds where a bull was kept with the cows and they had been in milk as much as eight months. The data in Table X show that with one exception these cows showed no oestrus until about a year after freshening. All the animals with the exception of E-37 either were in milk at the time purchased or had been milking until a recent date. Out of 14 cows purchased for experimental use, all of which had been in pasture with a bull, only 2 proved to be with calf. Examination showed that the ovaries of 7 of these cows were atrophied at the time of arrival at the experiment station.

TABLE X
DELAYED OESTRUM WITH MINERAL DEFICIENT COWS

No. of animal	Age, years	Date purchased	Condition	Date last calving	Date first oestrus
E-33.....	4	12/11-'23	In milk	Spring, 1923	6/21-'24
E-34.....	4	12/11-'23	Nearly dry	Spring, 1923	5/31-'24
E-35.....	Mature	12/11-'23	In milk	Spring, 1923	5/16-'24
E-36.....	4	12/11-'23	In milk	Spring, 1923	5/16-'24
E-37.....	2	12/11-'23	Not bred	9/19-'24
E-58.....	3½	9/19-'24	In milk	Spring, 1924	5/ 5-'25
E-59.....	Mature	9/19-'24	In milk	Spring, 1924	12/ 6-'24
E-60.....	2	11/ 3-'24	In milk	Spring, 1924	5/ 1-'25
E-61.....	2	11/ 3-'24	Dry	Spring, 1924	5/ 5-'25
E-62.....	2	11/ 3-'24	In milk	Spring, 1924	5/ 5-'25

It is recognized that the data were limited and that there is a possibility of other factors not controlled, but the evidence appears to justify the conclusion that the lack of ovulation for nearly a year was the result of malnutrition and that the mineral deficiency was the most probable cause. It may be noted from Table X that the cows, with one exception, finally showed ovulation in the early summer months. The fact that the animals received the basal ration only, removes any possibility of a utilization factor for minerals from grass which might be a factor in the appearance of oestrus in early summer in the case of the experimental animals. A mineral utilization vitamin from grass is also ruled out as the sole factor under pasturing conditions in the affected areas. The question may also be raised as to the possibility of better utilization of minerals due to the stronger ultra-violet rays in early summer. The most important observations suggesting this factor are that the cows used experimentally showed oestrus in early summer as indicated in Table X and that the mineral supplement used appeared to have had no immediate effect.

The general results of our experimental work, now covering three years, suggest another explanation. All severe cases that came under our observation were cows either in milk or at the end of a milking period or were growing animals. It is the general observation of farmers in the affected region that the heaviest producing cows suffer the most severely. It is well known that milk production is a heavy drain upon the mineral supply of the body. The experience of keeping cows on typical mineral deficient rations at the experiment station has been that dry cows even from the affected areas and presumably having a low storage do not show the symptoms. Cows in milk on the same ration show the symptoms readily in a few weeks. When the cows receiving a ration very low in phosphorus must supply this element for the milk, the body is undoubtedly called upon to make up the shortage, leaving the animal in a depleted condition. As a result of this depletion of minerals, ovulation is suspended during the milking period. After milk production ceases the animal usually is able slowly to replace the mineral reserve and when a certain point is reached, usually about a year from the time of freshening, oestrus appears. As a result of this condition, the cow is inclined to have a calf every other year, which is in line with an observation made by some of the farmers.

When making the surveys, difficulty was experienced in obtaining the information necessary to judge as to the prevalence of abortion as compared to other farming regions. The general impression from this source was that while the calf crop was decidedly short, perhaps not over 50 per cent some years, the condition was not the result of an unusual amount of abortion but rather of failure of cows to get in calf.

The facts probably are that on the farms where mineral deficiency occurs, ovulation is retarded to some extent, as was the case with the experimental animals. No cases of abortion have occurred among the cows on experiment. However, only two were kept for long periods while pregnant on the basal ration alone.

Effect of Magnesium Sulfate

The presence of large amounts of sulfate in the well water on all farms having mineral deficiency troubles attracted attention at once during the course of the survey. The analyses in Table III of the water samples from affected and unaffected farms show no significant relation between the sulfate content of the water and the mineral deficiency troubles. In Experiment II the addition of 16.47 grams of magnesium sulfate per 100 pounds of water apparently had no effect. Both the animals receiving the basal ration developed a depraved appetite, likewise the two receiving calcium carbonate; but E-34 and E-35, receiving the sodium phosphate supplement, showed no indication of abnormal conditions at the end of ten months.

In Experiment III the addition of 85 grams of magnesium sulfate daily to the ration received by E-35 (basal ration plus sodium phosphate) for an entire year was without apparent harmful effect. Adding bone-meal to the rations of 119 head of cattle in Experiment I prevented the occurrence of depraved appetite during the winter and spring of 1923-24 among these animals without changing their magnesium intake. While the evidence is by no means adequate to justify a definite conclusion, the indications are that sulfates are at least not the major factor in the case.

General Discussion of Results

The results of the experimental work bear out the conclusion, from the observations made in the survey, that the abnormal conditions in question are the result of a deficiency in the ration. The survey showed that legumes grow readily on the farms where the mineral deficiency is prevalent. Furthermore, the average CaO content of alfalfa grown on affected farms was 2.63 per cent; and for 9 samples from farms where trouble was not experienced, 2.23 per cent. Henry and Morrison give 1.95 per cent and Forbes 1.47 as the average CaO content of alfalfa hay, both figures decidedly below those for the hay from either affected or unaffected farms. In fact, only one sample out of 23 was lower than the average given by Morrison and none approached the Forbes figures. The calcium content of prairie hay is not high compared to that of legumes. The average of 0.60 per cent for 40 samples, however, is higher than the CaO content of a combination of corn fodder and timothy hay, which is the roughage received by thousands of dairy cows

without any symptoms of mineral deficiency. The addition of calcium carbonate supplements to the basal ration apparently was without effect either in preventing the onset of mineral deficiency or in curing it when present. No evidence is forthcoming from either the experimental results or the survey to indicate that the deficiency is one of calcium.

The relation of phosphorus appears to be definitely established. First, the soil of the region where these troubles appear is known to respond in a striking manner to the application of phosphorus fertilizers. The use of bonemeal as a supplement has been found to give certain relief when fed to cattle under practical conditions on the farms where trouble occurs. In one badly affected herd the addition of acid phosphate fertilizer to the grain ration overcame the condition. The samples of hay analyzed also show a decided deficiency in phosphorus.

McCollum considers 0.95 per cent phosphoric acid in the ration on the dry matter basis as the optimum for well being of laboratory animals. The actual phosphorus requirement of cattle is as yet unknown, but it is not improbable that the optimum is close to that of other animals. The prairie hay which constituted the greater part of the ration and in some cases the entire ration of cows in the affected regions, carried only 0.230 per cent of phosphoric acid, about one-fourth of the McCollum optimum amount.

The ration received by E-32 during the period of 285 days on the basal ration, consisted of 23 pounds of prairie hay and 9 pounds of oats. This ration supplied phosphoric acid at the rate of 0.41 per cent, or about half of the McCollum optimum. The results already given showed conclusively that the addition of phosphorus in the form of either tri-calcium phosphate or mono-basic sodium phosphate, prevented the appearance of symptoms in animals receiving the basal ration and caused the symptoms of deficiency to disappear in animals already affected.

In the literature reviewed, no cases are given in which calcium has been proved to be the only cause of mineral deficiency occurring with cattle under conditions of agricultural practice. In the report by Tuff (48) there are indications from the mineral content of the hay, as shown in Table XI, that the trouble might be attributed to a shortage of both calcium and phosphorus and such, apparently, is Tuff's opinion. No attempt was made to determine the facts on this point by feeding experiments. The view of Guthrie (15) appeared to be that the trouble reported by him was due to a shortage of lime, altho his analyses of grass would suggest phosphorus shortage also to be involved. In this case no experiments were made to determine the results of adding lime and phosphorus separately. Theiler, however, determined experimentally that a shortage of phosphorus was the cause of the serious deficiency condition made the subject of his extensive investigations.

TABLE XI
CALCIUM AND PHOSPHORUS CONTENT OF HAYS
Taken in connection with mineral deficiency investigations

	No. of samples	CaO	P ₂ O ₅
		Per cent	Per cent
Minnesota			
Affected farms, prairie hay.....	30	0.578	0.230
Affected farms, timothy hay.....	4	0.550	0.245
Affected farms, alfalfa hay.....	14	2.628	0.447
South Africa (Theiler)			
Affected area, hay.....	6	0.443	0.212
Norway (Tuff)			
Badly affected area, hay.....	3	0.250	0.142
Unaffected area, hay.....	1	0.880	0.440
Germany (Stohmann)			
Affected farms, hay.....	1	0.630	0.210
Unaffected farms, hay.....	1	0.900	0.430
Germany (Kellner)			
Affected farms, hay.....	5	0.829	0.258
Good hay (Wolf).....	1	0.950	0.430
Australia (Guthrie)			
Affected area, hay.....	4	0.378	0.274
Unaffected area, hay.....	2	0.558	0.414

The experimental results and the information from farmers show an important relation between mineral deficiency and reproduction. The effect noted was especially a delayed oestrus. It should be remembered that the ration received by the experimental animals selected as typical of the feeding practice in affected areas would not be classed as a good ration for dairy cows. It is by no means uncertain that other factors besides low phosphorus may be involved. It seems clear, however, that the ration is the chief factor in the situation. Cows fed liberally enough to gain freely, as did E-37, did not show oestrus for months and E-37 not for a year. Under conditions of ordinary farm practice cows are sometimes delayed in oestrus, but retained corpus luteum appears to be the usual cause. Poor condition of the animal does not necessarily cause delayed oestrus. The experimental animals, however, did not have retained corpus luteum but rather partial atrophy of the ovaries. Jordan (28) noted in his experiments, involving a ration extremely low in phosphorus, that oestrus stopped completely. Tuff (48) and Theiler (46, 47) as well as the New Zealand and Australian writers mention the serious reproductive troubles following phosphorus shortage. Delayed oestrus and small calf crops are especially emphasized. If delayed oestrus were a specific effect of phosphorus deficiency, one might expect a more prompt response when the deficiency is supplied. On the other hand, it is not improbable that with animals which had suffered so extremely from a mineral shortage some time would be required for them to return to normal. As noted in Table X, most of the animals showed first oestrus in May and June after having been in milk about a year. What is the significance of

this fact? As previously suggested, the possibility of the action of sunlight must be considered, as the strength of the ultra-violet rays is near maximum at this time. The data, however, are no more than suggestive. Further evidence will be necessary before much importance can be attached to this possibility. It is clearly established that green grass is an important factor in alleviating the mineral deficiency condition and probably in connection with reproduction as well. The facts learned in recent years concerning the relation of the antirachitic vitamin to mineral utilization make clear the probable cause of this effect. On some farms the animals do not recover so rapidly as on others. This is probably to be accounted for by a difference in the mineral content of the grass due to the soil. Low ground is especially low in available phosphorus and cows pastured on this type of soil show the least improvement.

While the experimental data do not indicate that the sulfate content of the water is the important factor causing the mineral deficiency trouble, the possibility of its being a contributing factor does not appear to be entirely eliminated. Information is available from two farms where alfalfa hay and a fair grain allowance were fed. On both these farms unmistakable symptoms of mineral deficiency were noted, on one especially severe. The water was especially high in magnesium sulfate. Balance experiments are needed to determine definitely if the sulfate is a factor.

The study of the problem is by no means complete. The fact that a shortage of phosphorus is the basis of the trouble has been established, but a number of important phases of the subject have been touched only incidentally in the course of the investigation.

Practical Considerations

The procedure in this investigation was arranged partly with the objective of obtaining information for practical use as soon as possible. The success of the feeding experiments with bonemeal shows clearly the practical procedure. The plan recommended is to allow the cattle free access to bonemeal regularly, as is done with common salt. With this opportunity the animal will eat a sufficient amount to meet the needs of the body. The co-operative experiment conducted on farms where conditions were especially bad showed that from 50 to 60 pounds of bonemeal fed in the manner indicated would supply a mature cow for a year. The bonemeal to be used is that prepared especially for animal feeding and should be finely ground. Fertilizer bonemeal has a pronounced odor and is not eaten so readily. The use of bonemeal, however, is a more or less temporary measure. The final solution of

the problem undoubtedly will be the general use of phosphorus fertilizers on these deficient soils, as a result of which the forage will furnish a sufficient supply of this element to make special methods of feeding unnecessary.

CONCLUSIONS

1. The condition of mineral deficiency among cattle in parts of Minnesota is caused chiefly by the lack of phosphorus in the roughages fed. It can be produced with cattle under controlled feeding on phosphorus deficient rations.

2. Calcium is not deficient in the roughages grown in the localities surveyed in Minnesota, tho it may be lacking in the roughages grown on certain sandy and peat soils.

3. Under Minnesota conditions, sulfates are not the major factor causing mineral deficiency with cattle.

4. Mineral deficiency troubles, the best known symptom of which is depraved appetite, or pica, are accentuated by the farm practice in the affected region of depending too much upon a ration composed largely of roughages for rapidly growing animals and lactating cows.

5. The data presented suggest that an insufficient amount of ultra-violet rays in the sunlight, and to some extent the lack of green feeds, may be accessory factors contributing to cause the seasonal incidence of depraved appetite.

6. Sterile feeding bonemeal (finely ground) given as a supplementary feed will cure and prevent this depraved appetite when fed with a fair dairy ration which includes access to common salt.

7. Cattle can utilize inorganic phosphorus compounds such as tricalcium phosphate and mono-basic sodium phosphate, when these are added to a ration deficient in phosphorus.

8. Under extreme conditions, as in the area studied, a shortage of phosphorus becomes a limiting factor in the economical utilization of feeds, and in the growth of cattle. The data reported bear out the generally accepted fact that phosphorus is involved in the intermediary metabolism of carbohydrates.

9. Our data corroborate the results obtained by earlier investigators, that it is not possible to affect significantly the composition of milk ash by feeding a ration deficient in phosphorus.

10. Milk flow is eventually reduced by the lack of phosphorus in the feed.

11. Marked inhibition of oestrus was observed with the experimental cows which had been on phosphorus deficient feeds. Our data suggest that this inhibition was caused by the lack of phosphorus. The low intensity of ultra-violet light during the winter months and the lack of a factor supplied by green feeds may also have been more or less involved.

12. The feeding of bonemeal or spent boneblack is the most economical method now known to cure and prevent this particular condition of mineral deficiency. The method which will finally come into use is the application of phosphate fertilizers to the pasture and hay lands of the affected areas.

13. The phosphorus content of alfalfa and prairie hays is affected directly by the soil and by the amount of rainfall during the growing season.

LITERATURE CITED

1. Aston, B. C. Bush or tanganda disease. 13th Ann. Rept., N. Zeal. Dept. Agr., 81. 1905; 14th Ann. Rept., 107-114. 1906; 20th Ann. Rept., 75-78. 1912.
Bush sickness investigations: Five years' work at the Mamaku Demonstration Farms. N. Zeal. Jour. Agr., 28:215-238, 301-305, 381-390. 1924; 29:84-91. 1924.
2. Ames, J. W., and Boltz, G. E. Nitrogen and mineral constituents of the alfalfa plant. Ohio Exp. Sta. Bul. 247, pp. 755-773. 1912.
3. Ames, J. W., Boltz, G. E., and Stenius, J. A. Effect of fertilizers on the physical and chemical properties of wheat. Ohio Exp. Sta. Bul. 243, pp. 567-587. 1912.
4. Bauer, H. Knochenerweichung beim Rinde. Wochensch. f. Thier. u. Viehzucht, 12:334-335. Abstract in Jahresber. Agr. Chem., 12:546. 1868.
5. Becker, R. B. Thesis for M.S. degree, Iowa State College. 1920.
6. Dorno, C. Physik den Sonnen- und Himmelstrahlung. Braunschweig. 1919.
7. Elliott, H. B. Personal experience of osteoporosis. Jour. Comp. Path. and Ther., 12:300-307. 1899.
8. Eckles, C. H., and Swett, W. W. Some factors influencing the growth of dairy heifers. Mo. Exp. Sta. Res. Bul. 31, pp. 3-56. 1918.
9. Forbes, E. B., Whittier, A. C., and Collison, R. C. The mineral nutrients of bluegrass. Ohio Exp. Sta. Bul. 222, pp. 39-52. 1910.
10. Forbes, E. B. Effects of fertilizers on the composition of foods. Ohio Exp. Sta. Tech. Bul. 5, pp. 95-101. 1914.
11. Grimmer, W. Chemie and Physiologie der Milch. Paul Parey, Berlin. pp. 178-192. 1910.
12. Gohren, T. von. Ueber eine Beigabe von Knochenerde zum Futter der Thiere, nebst einem physiologisch-chemischen Versuch über deren Verdaulichkeit. Landw. Vers. Sta., 3:161-178. 1861.
13. Golding, J., and Paine, S. G. Notes on the composition of milk yielded by cows fed on pasture manured with phosphate and potash. Analyst, 35:246-247. 1910.
14. Grouven, H. Abstract in Jahresber. Agr. Chem., 12:544. 1868.
15. Guthrie, F. B., Henry, M., Jensen, H. I., and Ramsay, A. A. Notes on osteomalacia (bone-chewing). N. S. Wales Dept. Agr. Sci. Bul. 12, pp. 3-23. 1914.
16. Hall, C. W., Meinzer, O. E., Fuller, M. L. U. S. Geol. Survey, Water Supply Paper 256, p. 251. 1911.
17. Hart, E. B., Steenböck, H., and Humphrey, G. C. New facts on feeding cattle for successful growth and reproduction. Wis. Exp. Sta. Bul. 287, pp. 3-24. 1918.

18. Hart, E. B., Steenbock, H., Elvehjem, C. O., Scott, A., Humphrey, G. C. The influence of sunlight upon calcium equilibrium. *Jour. Biol. Chem.*, **62**:371-383. 1926.
19. Hart, E. B., Steenbock, H., and Hoopert, C. A. I. The comparative influence of green and dried plant tissue, cabbage, orange juice, and cod liver oil on calcium assimilation. *Jour. Biol. Chem.*, **48**:33-50. 1921.
20. Hart, E. B., Steenbock, H., Hoopert, C. A., and Humphrey, G. C. II. The comparative efficiency of dry and green alfalfa in maintaining calcium and phosphorus equilibrium in milking cows. *Jour. Biol. Chem.*, **53**:21-30. 1922.
21. Hart, E. B., Steenbock, H., Humphrey, G. C., and Hulce, R. S. New observations and a new interpretation of old observations on the nutritive value of the wheat plant. *Jour. Biol. Chem.*, **62**:315-322. 1924.
22. Hart, E. B., Steenbock, H., and Elvehjem, C. A. The effect of light upon calcium and phosphorus equilibrium in mature lactating animals. *Jour. Biol. Chem.*, **62**:117-131. 1924.
23. Hart, E. B., and Steenbock, H. The effect of a high magnesium intake on calcium retention by swine. *Jour. Biol. Chem.*, **14**:75-80. 1913.
24. Henry, M. Osteomalacia in cattle in New South Wales. *Agr. Gaz. N. S. Wales*, **23**:885-888. 1912.
25. Hunt, C. H., Winter, A. R., and Miller, R. C. A possible factor influencing the assimilation of calcium. *Jour. Biol. Chem.*, **55**:739-742. 1923.
26. Hunt, C. H., Winter, A. R., Schulz, J. A., and Miller, R. C. The mineral metabolism of the dry and lactating goat. *Amer. Jour. Physiol.*, **66**:349-362. 1923.
27. Ibele, J. Lecksucht, Pseudoecksucht und 'Sucht zu lecken' beim Rinde und deren Bekämpfung. *Mitt. Ver. Förd. Moorkult. Deut. Reiche*, **36**:14-17. 1918.
28. Jordan, W. H., Hart, E. B., and Patten, A. J. A study of the metabolism and physiological effect of certain phosphorus compounds with milch cows. *Amer. Jour. Physiol.*, **16**:268-313. *N. Y. Exp. Sta. Tech. Bul.* 1, pp. 3-59. 1906.
29. Karmrodt, C. Abstract in *Jahresber. Agr. Chem.*, **12**:545. 1868.
30. Kellner, O., Kohler, A., and Barnstein, F. Untersuchungen verschiedener Rauhfutterarten aus Wirtschaften in denen Knochenbruchigkeit auftritt. *Sächs. Landw. Ztschr.*, **42**:167-171; **227**. *Biedermann's Zentbl.*, **24**:441-443. 1894.
31. König, J., and Karst, H. Der Einfluss des Bodens und der Dungung auf die Zusammensetzung der Pflanzen. Ein Beitrage zur Geschichte der Lecksucht. *Landw. Verst. Sta.*, **100**:269-314. 1923.
32. Leverett, Frank. Surface formations and agricultural conditions of Northwestern Minnesota. *Minnesota Geological Survey, Bul* 12. 1915.
33. LeClerc, J. A., and Breazeale, J. F. Plant food removed from plants by rain and dew. *U. S. Dept. Agr. Yearbook*, pp. 389-402. 1908.
34. Malcolm, J. On the inter-relationship of calcium and magnesium excretion. *Jour. Physiol.*, **32**:183-190. 1905.
35. Meigs, E. B., and Woodward, T. E. Influence of calcium and phosphorus in the feed on the milk yield of dairy cows. *Jour. Dairy Sci.*, **4**:185-217. 1921.
36. Miles, L. M., and Feng, C. T. Calcium and phosphorus in osteomalacia. *Jour. Exp. Med.*, **41**:137-157. 1925.
37. Miller, H. G., Brandt, P. M., and Jones, R. C. Mineral metabolism studies with dairy cattle. *Amer. Jour. Physiol.*, **69**:169-176. 1924.

38. Miller, H. G., Yates, W. W., Jones, R. C., and Brandt, P. M. Mineral equilibrium after prolonged lactation. *Amer. Jour. Physiol.*, 72:647-654. 1925.
39. Murphy, E. W. Treatment of pastures. Prevention of rickets, cripples, and paralysis. *Jour. Dept. Agr. Victoria*, 15:449-456. 1917.
40. Nessler, J. II. Untersuchungen der Knochen von knochenbruchigkeitem Rindvieh. *Landw. Vers. Sta.*, 16:187-196. 1873.
41. Price, O. B. The mineral content of alfalfa increased by fertilization. *Mich. Exp. Sta. Quar.*, 5:159. 1923.
42. Reakes, C. J. A bone disease of sheep. 18th Ann. Rept., N. Zeal. Dept. Agr., 47-52. 1910.
Bush sickness investigations. 20th Ann. Rept., 72-75. 1912; 21st Ann. Rept., 43-46. 1913; 22nd Ann. Rept., 35-37. 1914.
A preventative lick for bush sickness. *N. Zeal. Jour. Agr.*, 11:228. 1915.
Bush sickness, Work at the Mamaku Farm. *N. Zeal. Jour. Agr.*, 11:377-383. 1915.
Cows chewing wood. *N. Zeal. Jour. Agr.*, 16:57. 1918.
43. Schmidt, H. Field and laboratory notes on a fatal disease of cattle occurring on the coastal plains of Texas (loin disease). *Tex. Exp. Sta. Bul.* 319, pp. 5-32. 1924.
44. Steenbock, H., Hart, E. B., Elvehjem, C. A., and Kletzien, S. W. I. The antiscorbutic properties of hays as related to climatic conditions with some observations on the effect of irradiation with ultra-violet light. *Jour. Biol. Chem.*, 66:425. 1925.
45. Stohmann, F. Ueber Knochenbruchigkeit erzeugendes Heu. *Ztschr. Landw. Zentbl. Ver. Prov. Sachsen*, 9. Abstract in *Jahresber. Agr. Chem.*, 12:546. 1869.
46. Theiler, A. The cause and prevention of lamziekte. *Jour. Dept. Agr. (Union S. Afr.)*, 1:221-247. 1920.
47. ———, Green, H. H., and du Toit, P. J. Phosphorus in the livestock industry. *Jour. Dept. Agr. (Union S. Afr.)*, 8:460-504. 1924.
48. Tuff, P. Osteomalacia and its occurrence in cattle in Norway. *Jour. Comp. Path. and Ther.*, 36:143-155. 1923. *Proc. World's Dairy Congr.*, 2:1494-1501. 1923.
49. Welch, H. Bone chewing by cattle. *Mont. Exp. Sta. Circ.* 122, pp. 1-8. 1924.
50. *Mich. Exp. Sta. Quar. Bul.* 7. 1924; *U. S. Dept. of Agr., B. A. I.*, 15th Ann. Rept., p. 530. 1898; *Ohio Exp. Sta. Bul.* 330. 1918; *Penn. Dept. Agr. Ann. Rept.*, 34-131. 1898; *Amer. Vet. Rev.*, 20:28-39. 1896; *The Dairy Farmer*, 21, 46. 1923.
51. *Agr. Gaz. N. S. Wales*, 10:235. 1899; *Aust. Farm and Home*, 5:57. 1896; *Jour. Dept. Agr. Victoria*, 9:71-75. 1911; *Jour. Dept. Agr. Victoria*, 1:774-784. 1902.