The effect of trace mineral supplements upon the performance of wintering and fattening heifers
by Jack L Clark

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Animal Science
Montana State University

Abstract:
Four experiments were conducted to determine the effect of minerals upon the performance of wintering and fattening cattle under drylot conditions.

Experiment I was conducted with 32 Hereford heifer calves fed for 144 days. The calves were fed a ration of 80 percent steam rolled barley and 20 percent beet pulp ad libitum, and three pounds of grass hay daily. In addition, two pounds of a twenty percent protein supplement was fed. This supplement was the carrier for the trace minerals. Lot 5 received trace mineral; Lot 6, no trace mineral; Lot 7, chelated trace mineral; and Lot 8, trace mineral with high zinc. There was no difference in weight gains among lots. The heifers fed trace minerals with high zinc required 6.5 percent less feed per pound of gain than the control heifers. There was little difference in carcass grades between lots of heifers.

In Experiment II, III, and IV, the amount of trace minerals furnished in the supplement was increased over that used in Experiment I. The amount of minerals supplied per pound was as follows: trace mineral, Mn, 200 mg.; Zn, 41 mg.; Fe, 300 mg,; Cu, 60 mg.; Co, 10.4 mg.; and I, 13.6 mg. The trace mineral with high zinc furnished the same as trace mineral, except the zinc level was 545 mg. per pound. The chelated trace mineral furnished the following: Mn, 15 mg.; Zn, 19.5 mg,; Fe, 14.5 mg.; Cu, 4.4 mg.; Go, 3.7 mg.; and I, 7.7 mg.

In Experiment II, 38 head of heifer calves were wintered for 84 days on grass hay and a barley:beet pulp ration. The trace minerals were added as above by feeding one pound of a protein supplement. There was no significant difference in gain among lots. There was an increase in feed efficiency of 5 and 12 percent for heifers fed the high zinc and chelated trace minerals, respectively.

In Experiment III, the calves in Experiment II were continued onto a fattening ration for 135 days, staying on their respective treatments. The fattening ration consisted of a mixture of 80 percent barley, 20 percent beet pulp fed ad libitum, and three pounds of grass hay. There was no significant difference in gain. However, heifers fed the high zinc were slightly more efficient than the control heifers. The daily feed intake of heifers was increased in all trace mineral supplemented lots.

Experiment IV was conducted with 32 yearling heifers fed a fattening ration for 125 days. The treatment and rations were the same as used in Experiment III. There was a significant increase in gain ($P<.05$) of the trace mineral supplemented heifers over the control lot. There was no difference in gain among the trace mineral lots. There was also an increase in daily feed intake and feed efficiency in favor of the trace mineral supplemented heifers. There was little difference in carcass grades between lots, however, heifers fed the trace mineral and the trace mineral with high zinc had higher dressing percents than the controls.

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of

MASTER OF SCIENCE

in

Animal Science

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June, 1965

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. O. O. Thomas for his sincere and invaluable guidance throughout my graduate program, in the organization and conduction of the experiments and his suggestions in the preparation of the manuscript. The author also expresses appreciation to Dr. E. P. Smith and R. F. Eslick for their advice and suggestions with the manuscript and analysis of data.

Sincere appreciation is expressed to my wife, Peggy, for her help, understanding, and encouragement during my graduate work.

Appreciation is also expressed to the graduate students, student workers, and farm crew for their help in collecting the data.

Appreciation is also expressed to the Calcium Carbonate Company and Van Waters and Rogers, Incorporated for supplying the trace minerals for these experiments. Appreciation is also expressed to Mattox and Moore for supplying the vitamin A injections used in Experiment I.

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ABSTRACT

Four experiments were conducted to determine the effect of minerals upon the performance of wintering and fattening cattle under drylot conditions.

Experiment I was conducted with 32 Hereford heifer calves fed for 144 days. The calves were fed a ration of 80 percent steam rolled barley and 20 percent beet pulp ad libitum, and three pounds of grass hay daily. In addition, two pounds of a twenty percent protein supplement was fed. This supplement was the carrier for the trace minerals. Lot 5 received trace mineral; Lot 6, no trace mineral; Lot 7, chelated trace mineral; and Lot 8, trace mineral with high zinc. There was no difference in weight gains among lots. The heifers fed trace minerals with high zinc required 6.5 percent less feed per pound of gain than the control heifers. There was little difference in carcass grades between lots of heifers.

In Experiment II, III, and IV, the amount of trace minerals furnished in the supplement was increased over that used in Experiment I. The amount of minerals supplied per pound was as follows: trace mineral, Mn, 200 mg.; Zn, 41 mg.; Fe, 300 mg.; Cu, 60 mg.; Co, 10.4 mg.; and I, 13.6 mg. The trace mineral with high zinc furnished the same as trace mineral, except the zinc level was 545 mg. per pound. The chelated trace mineral furnished the following: Mn, 15 mg.; Zn, 19.5 mg.; Fe, 14.5 mg.; Cu, 4.4 mg.; Co, 3.7 mg.; and I, 7.7 mg.

In Experiment II, 38 head of heifer calves were wintered for 84 days on grass hay and a barley:beet pulp ration. The trace minerals were added as above by feeding one pound of a protein supplement. There was no significant difference in gain among lots. There was an increase in feed efficiency of 5 and 12 percent for heifers fed the high zinc and chelated trace minerals, respectively.

In Experiment III, the calves in Experiment II were continued onto a fattening ration for 135 days, staying on their respective treatments. The fattening ration consisted of a mixture of 80 percent barley, 20 percent beet pulp fed ad libitum, and three pounds of grass hay. There was no significant difference in gain. However, heifers fed the high zinc were slightly more efficient than the control heifers. The daily feed intake of heifers was increased in all trace mineral supplemented lots.

Experiment IV was conducted with 32 yearling heifers fed a fattening ration for 125 days. The treatment and rations were the same as used in Experiment III. There was a significant increase in gain ($P < .05$) of the trace mineral supplemented heifers over the control lot. There was no difference in gain among the trace mineral lots. There was also an increase in daily feed intake and feed efficiency in favor of the trace mineral supplemented heifers. There was little difference in carcass grades between lots, however, heifers fed the trace mineral and the trace mineral with high zinc had higher dressing percents than the controls.

INTRODUCTION

Cattle feedlot operators are, at present, receiving lower net returns on their cattle. This lower return greatly emphasizes the importance of providing means for increasing gain and feed efficiency in cattle. Little is known about the need for trace minerals in feedlot rations in Montana. There has also been little work with trace minerals using barley as the chief basal component of the diet. Many experiment station tests have shown some need for trace minerals when corn was the main component of the diet.

The addition of trace mineral supplements to the ration is relatively inexpensive. Thus, if a response in terms of weight gain and feed efficiency could be obtained with the use of trace mineral supplements, they would be of importance in increasing the net returns of the feeders. Chelated trace minerals have been used in monogastric animals to obtain increases in gain and feed efficiency. These minerals are more expensive per pound than the common trace minerals, but smaller amounts are recommended to be added to the ration.

Because trace minerals may be of importance in beef cattle rations, there is a need to determine if a response will be obtained by adding these minerals. The objectives of the experiments reported in this manuscript were to evaluate the use of trace minerals for feedlot cattle in Montana.

The trace minerals used in these studies were commercial trace mineral mixtures commonly used in commercial feeds.

REVIEW OF LITERATURE

Many minerals have been found to occur in animal tissues. These minerals are generally regarded as either macro- or micro-nutrients. According to Lamb _et al._ (1957) in animal physiology, it is customary to regard any element which normally occurs in, or is required by, the higher forms of animal life in amounts greater than those of iron as a macro-nutrient and to include among the micro-nutrients all those elements which normally occur or are required in amounts no greater than those of iron. Morrison (1959) stated that as late as thirty years ago, little was known about the need for any of this micro-minerals. Of the micro-nutrient minerals, iron, copper, zinc, manganese, cobalt, and iodine are necessary for animal life (Gilbert 1948).

THE BIOLOGICAL FUNCTIONS OF MINERALS

The biological functions of minerals were classified by Mitchell (1947) as follows: (1) minerals contribute to the structure of the body, (2) minerals participate in the functional activities of the body, such as muscular activities, (3) they aid in maintaining the _status quo_ of the tissues already formed against the constant erosion of the life processes, and (4) as integral parts of enzyme systems in the tissues, minerals aid materially in the metabolizing of organic food nutrients.

EXPERIMENTAL EVIDENCE OF THE NEED FOR TRACE ELEMENTS

Cobalt

Cobalt is needed for the production of vitamin B_{12} by the rumen microorganisms (Underwood 1962).

According to the NRC requirements (1963), the believed cobalt requirement of beef cattle falls between 0.07 and 0.10 mg. per 100 pounds body weight. Lamb et al. (1957) stated that one mg, of cobalt per day for an adult cow will be satisfactory. Tillman (1964) reported that beef cattle require 0.07 parts per million (ppm) of cobalt daily.

Apparently all feedstuffs are not adequate in cobalt content. Hale et al. (1950), using chicks as an assay animal, determined the relative amount of vitamin B_{12} in the rumen of a cobalt deficient sheep as compared to a cobalt treated animal. In the assays, there was an average difference of 42 grams of growth, favoring the cobalt supplemented sheep, when chicks were fed ingesta from the two sheep. These data tend to show that vitamin B_{12} production was limited in the rumen of the cobalt deficient sheep when compared to the production of the vitamin in the rumen of the cobalt-fed sheep.

Keener and Percival (1950) reported that sheep supplemented with cobalt gained approximately seven times as much in weight, were eating five times as much concentrates, six times as much hay, and were drinking twice as much water as cobalt deficient animals. Klosterman et al. (1951) found that the addition of cobalt to a ration, containing wheat straw, cane molasses, field peas, and cerelose, significantly increased ($P < .05$) the value of protein for growing ewe lambs.

In a fattening ration composed of sorghum silage, ground corn, and soybean meal, Tsien et al. (1960) found that adding a 20 mg. bullet containing 90 percent cobalt oxide significantly increased ($P < .01$) the gains of cattle. Feeding cobalt in soybean meal at the rate of 0.75 mg. per day for the first 90 days and then 1.5 mg. for the last 80 days produced average daily gains of 2.00 pounds compared to 1.70 pounds for the control lot, when cattle are fed a sorghum grain, alfalfa hay ration (Koch et al. 1961). This difference was significant ($P < .01$). In grazing trials, cattle fed 0.8 mg. of cobalt daily gained 189 pounds compared to 153 pounds for the control group (Chapman and Kidder 1963). However, this difference was non-significant ($P > .05$).

Not all workers have obtained an increase in production by supplementing cobalt. Smith et al. (1961) reported that when grazing steers consumed 0.38 mg. of cobalt daily, there was no increase in average daily gain. Embry and Dittman (1961) and Thomas et al. (1961) obtained no increase in gain when cobalt bullets were administered to grazing yearling steers.

Lamb et al. (1957) found that 100 mg. of cobalt may be fed per day to cows and not be toxic. Salsbury et al. (1956) reported that 12 ppm of cobalt caused some depression of cellulose digestion in vitro, and 100 ppm of cobalt caused a pronounced depression. McNaught et al. (1950), also working with in vitro studies, found that rumen bacteria were able to tolerate 10 ppm of cobalt but 1000 ppm inhibited bacterial growth.

It has been reported by Keener et al. (1951) that cobalt in the form of carbonate was absorbed in appreciable quantities as indicated by its presence in the blood and urine. Keener and Percival (1950) had reported that both cobalt carbonate or sulfate would relieve a cobalt deficiency in sheep. An intravenous injection of cobalt sulfate brought about a slow response, in deficient animals, if administered daily or in large quantities twice a week.

Copper

Copper is known to have many functions. According to Underwood (1962), copper is important in the production of hemoglobin, the processes of pigmentation of hair and wool, and myelination of the spinal cord. Copper is also present in the oxidative enzymes at cellular level, needed for proper bone formation, keratinization of wool, and normal reproduction.

According to the NRC (1963) standards for beef cattle, the daily requirement of copper is between two and four mg. per pound of total air dry feed. Tillman (1961) noted that beef animals require five ppm of copper. Tillman (1964) stated that requirements of copper are 5 to 10 ppm.

Although the requirements of copper are small, feedstuffs are known to be deficient. The use of copper supplements for curing or preventing diseases such as "swayback" and "falling disease" in sheep has been practiced for some time (Gilbert 1948). Arthur et al. (1959) found that a conditioned copper deficiency in cattle in Eastern Ontario is alleviated by feeding two grams of copper sulfate per animal daily.

When copper, cobalt and manganese were fed free choice to calves, Dent et al. (1956) obtained an increased daily gain of 0.3 pound which was significant at the 10 percent level. There was also increased feed consumption as well as increased feed efficiency.

Considerable research has been carried out concerning the toxicity of copper. Chapman et al. (1962) administered to steers 0.5, 1.0, 2.0, 4.0, 8.0, grams of copper sulfate daily in a gelatin capsule. It was found that administering copper sulfate in this manner was not toxic. Increasing the level of copper sulfate to 12 grams daily did not create a toxic syndrome. However, when 12 grams of copper sulfate was administered in a water drench, the copper sulfate was toxic. Kidder (1949) reported that a 500 pound steer developed chronic copper poisoning and died in 122 days when five grams of copper sulfate was given daily as a drench. It has also been reported (Anonymous 1957) that 0.25 grams of copper per day per 1000 pounds of body weight produces a toxicity in cattle.

Arthur et al. (1959) has reported that three to five grams of copper sulfate daily for three years showed no ill effects. According to McNaught et al. (1950) rumen bacteria will tolerate 10 ppm of copper but the bacteria are inhibited by 25 ppm of copper.

It appears that the form in which copper is administered to the animal is important. Lassiter and Bell (1960) reported that the concentration of copper in blood and plasma was significantly higher ($P < .05$) after oral administration of copper chloride than after copper sulfate, copper nitrate or cupric oxide needles. Lassiter also found that the copper concentration of blood and plasma was higher after use of the oral carbonate source compared to the copper oxide source. Chapman and Bell (1963) in a series of experiments determined the availability of copper from several sources using Cu-64 labeled compounds. Cupric oxide powder had a relatively low absorption rate and a high rate of fecal excretion. Cupric oxide needles and copper wire had a low absorption rate, but passed slowly through the body. Cuprous oxide had a moderate rate of absorption, but a high rate of urinary excretion. Cupric carbonate had the highest rate of absorption, but also the highest rate of excretion. Copper sulfate had a moderate rate of absorption and had a low excretion rate indicating a favorable retention. Cupric nitrate and copper chloride compared favorably with copper sulfate.

Iron

According to Underwood (1962), iron is concerned in the oxidative mechanism of all cells. Iron is also important in oxygen transport as part of the hemoglobin molecule, and it is present in iron containing flavo-proteins.

The iron requirements for cattle are unknown (NRC 1963). However, according to Tillman (1961 and 1964), the iron requirement of beef cattle is 80 to 150 ppm. Underwood (1957) stated that no true iron deficiency has ever been recorded except in pigs. This seems to be the case as Bentley et al. (1954), Smith et al. (1964), and Kolari and Harvey (1964) failed to get an added response when iron was added to rations for cattle. However, Hoefer et al. (1958) obtained an increased daily gain of 0.31 pounds when pigs were supplemented with 100 ppm of iron.

McNaught et al. (1950) found that rumen bacteria will tolerate 100 ppm of iron but 1000 ppm will inhibit the bacteria.

Manganese

Manganese is involved in the calcification of bone (Underwood 1962). Manganese is also important in reproduction and it has a lipotrophic action. Manganese in the animal may also be concerned with the development of the pituitary gland and the regulation of the sex glands (Gilbert 1948).

Manganese requirements of beef cattle are uncertain but appear to be met with as little as 2.7 to 4.5 mg. per pound in the air-dry ration (NRC 1963). Tillman (1964) stated that the manganese requirement is 15 to 30 ppm. Since many roughages contain 22.5 to 67.5 mg. per pound of manganese on a dry basis, and grains other than corn contain 6.75 to 22.5 mg. per pound, it seems unlikely that most beef cattle rations require manganese supplementation (NRC 1963). However, when Lassiter and Alligood (1963) fed either 3.4 or 7.5 mg. of manganese per pound of a corn, soybean meal and hay ration to cattle, there was a significant difference ($P < .01$) in digestibility between the two treatments in favor of the latter.

Rojas and Dyer (1964) observed that all calves born to manganese deficient dams were deformed. The ration of the deficient dams contained 15.8 ppm of manganese. Chamberlain and Burroughs (1962) found that when manganese was omitted from the rumen medium that cellulose digestion decreased. Chamberlain's data suggested that there were two possible pathways for cellulose degradation; one way is to make use of the manganese or magnesium ion, while the alternate pathway doesn't make use of either of these ions. However, Hubbert et al. (1958) obtained no increase in cellulose digestion when manganese was added to a manganese deficient medium.

Embry et al. (1958), working with cattle, obtained no added response when 30 ppm of manganese was added to a ration containing 15 ppm of manganese. There was also no response when up to 1000 ppm of manganese was added to a corn, cottonseed meal, molasses ration for cattle (Robinson et al. 1963). At the higher levels of manganese, iron absorption and fiber digestibility were reduced.

Cunningham et al. (1962) found that feeding up to 818 ppm of manganese to calves would not adversely affect weight gains, feed efficiency or feed intake. Hansard et al. (1960), studying the effects of high manganese on rats, reported that either 500 or 1000 ppm of manganese depresses growth and iron absorption. Hansard also stated that excess daily manganese added to a low phosphorus diet drastically reduces iron utilization by the red blood cells.

Zinc

According to Underwood (1962) zinc is a constituent of the enzymes carbonic anhydrase, carboxy peptidase, alkaline phosphatase, and alcohol dehydrogenase. Zinc is also a cofactor of many other enzymes as well as being needed for proper kertinization of the skin. Gilbert (1948) stated that zinc is also a constituent of insulin crystals.

Zinc requirements have not been established for beef cattle (NRC 1963). Tillman (1961 and 1964) has reported, however, that the requirement of beef cattle is 30 ppm.

It has only been recently that research has shown a need for supplemental zinc in cattle. Zinc supplementation of beef cattle rations may also become increasingly more important with greater use of high-concentrate feeds (Anonymous 1964). Miller and Miller (1960) found that calves on a diet containing 2.7 ppm of zinc developed a zinc deficiency, while animals receiving 46 ppm zinc remained normal. The body weight gain per week was approximately 10.5 pounds for the calves receiving 46 ppm zinc and 8.0 for calves receiving 2.7 ppm zinc. Miller and Miller (1962) observed that calves receiving a purified basal diet developed parakeratosis, while calves receiving the basal plus 43 ppm of zinc remained normal. It was also found that adding 260 ppm zinc to zinc deficient animals brought about recovery.

Smith et al. (1962) obtained significant differences ($P < .01$) in gain with lambs when 100 ppm zinc was added to a basal ration containing 2.7 ppm zinc. The daily gains were 0.06 pounds for the basal ration and 0.54 pounds for the zinc supplemented ration. Ott et al. (1964) also obtained significant increased (P<.01) daily gain and feed efficiency in lambs when zinc was added to the basal ration.

According to Legg and Spears (1960), cows that had body lesions similar to those produced on rats fed zinc deficient diets, were fully recovered in three weeks after zinc sulfate was administered. Green et al. (1962) has reported a significant increased (P<.01) gain and feed efficiency when zinc was added to the diets of pigs. Miller et al. (1962), working with calves, obtained no response when zinc was added to the diet. McElroy (1964) also failed to get a response in rate of gain or feed efficiency when zinc oxide was added to the ration of steers.

"High" Levels of Zinc

Ott et al. (1963) reported that when 100 ppm of zinc was added to a basal ration containing 2.7 ppm zinc, the daily gain of calves was increased from 0.54 pounds to 1.20 pounds, and the feed required per 100 pounds of gain was 993 and 392 pounds respectively. Hoaranen and Hyppola (1961) reported that feeding 100 mg. of zinc per day per 100 pounds of body weight, prevented itching and hair sticking in dairy cows. These symptoms were associated with reduced milk production.

Beeson et al. (1962) found that adding 100 ppm of zinc to a basal ration containing 24 ppm of zinc increased gain of steers by 17 percent, feed consumption by 5.1 percent and feed efficiency by 11 percent. The difference in gain was significant (P<.05).

Smith et al. (1964) reported a significant increase in gain (P<.05) when 1205 mg. or 2205 mg. of zinc per day was fed to steers compared to a level of 196 mg. per day. There was, however, no effect on carcass grades or dressing percent. Results by Wise and Barrick (1963) and Oltjen and Davis (1963) showed no response when 100 ppm of zinc was added to the basal ration of cattle.

Cox and Hale (1962) found that neither 0.2 or 0.4 percent zinc in the diet of swine produced signs of marked toxicosis, nor had an adverse effect on growth or feed consumption. Brink et al. (1959) reported that up to 0.1 percent zinc in the diet of weanling pigs is not toxic. However, 0.2 percent zinc in the diet was toxic since it depressed daily gains and feed intake. When 0.8 percent of the diet was zinc, there was body weight loss and a severely depressed feed intake. According to Hansard et al. (1957), the addition of zinc at 0.5 or 1.0 percent of the diet caused a marked decrease in net retention and in the apparent and true digestibility of calcium in sheep.

TRACE MINERALS IN COMBINATION

Although an individual element will, in many cases, not give a response, as reported previously, a combination of more than one element may give a response. Underwood (1957) reported that the dietary level as well as the proportion of trace minerals are extremely important. In many experiments where alfalfa ash or molasses ash were used as a supplement, there was an increase in production which may be due to the trace minerals in the ash (Klosterman et al. 1953, Bentley et al. 1952, Bentley et al. 1954). Bentley et al. (1954) found that when either alfalfa ash or trace minerals were added to steer rations that the average daily gain was significantly increased ($P < .05$): 1.34 pounds for basal, 1.96 pounds for basal plus trace minerals, and 1.89 pounds for basal plus ash. There was also an increase in feed efficiency and consumption.

Lassiter et al. (1958) working with dairy heifers, added alfalfa ash to a ration containing corn cobs plus 5.6 pounds of a soybean meal-grain mixture. The supplemented heifers gained 1.47 pounds daily compared to 1.26 pounds for the control group. The supplemented group also required less feed per pound of gain, 12.40 compared to 14.70 for the control group.

Nicholson et al. (1960) reported that alfalfa ash increased the rate of digestion and efficiency in calves. Swift et al. (1951) working with sheep, found that alfalfa ash increased the mean digestibility of every ration constituent; however, only the digestibility of crude fiber was found to be significant ($P < .01$). Chappel et al. (1955) also found that alfalfa ash significantly increased ($P < .01$) the digestibility of crude fiber as well as organic matter in sheep.

Bentley and Moxon (1952) added trace minerals to a basal ration of corn cob meal, and poor timothy hay and obtained a 43 percent increase in gain with calves. When trace minerals were added to a corn, prairie hay, soybean meal ration, for steers, the average daily gain was 3.52 pounds for the controls and 3.78 pounds for the trace mineral supplemented group (Koch et al. 1960). The carcass grades were about the same between groups. Smith et al. (1959) supplied trace minerals to a corn, prairie hay ration for fattening cattle in the following amounts per day: cobalt, 1.25 mg.; copper, 3.65 mg.; iodine, 1.97 mg.; iron, 46.13 mg.; manganese, 56.3 mg.; and zinc, 3.42 mg. There was an improvement of 0.33 pounds of gain per day with the addition of trace minerals. Oltjen et al. (1959) fed the same levels of trace minerals as above and obtained a significant increase

($P < .01$) in gain with fattening cattle. There was also an increase in consumption and efficiency of gain. Oltjen et al. (1958) obtained gains of 2.51 pounds per day for controls and 2.88 pounds per day for Hereford heifers when the rations were supplemented with trace minerals. The carcass data were similar between lots.

Carmack et al. (1960) found that adding trace minerals to a fattening ration for calves, containing either corn or sorghum grain, significantly increased ($P < .05$) gains. Nelson et al. (1957) observed that steers on range grass supplemented with cottonseed meal had greater gains than when part of the cottonseed meal was replaced with urea as a protein source. When trace minerals were present in the urea supplement, there was no difference in gains. Nelson also noted that the steers utilized little if any of the urea without the addition of trace minerals. Thomas et al. (1953) found that steers supplemented with soybean meal gained significantly faster ($P < .01$) than steers supplemented with urea. However, when trace minerals were added to the urea there was no difference in gain of steers when supplemented with the urea or soybean meal. Klosterman et al. (1956) fed a full feed of ground ear corn and two levels of protein, 1.5 pounds or 0.75 pounds of soybean meal per day to fattening cattle. Trace minerals were added as follows per day: iron, 800 mg.; manganese, 200 mg.; copper, 25 mg.; zinc, 14 mg.; and cobalt, 0.5 mg. The addition of the trace minerals significantly increased ($P < .05$) the rate of gain at both protein levels. However, the increase was greater at the higher protein level. Klosterman noted that the lower protein ration was deficient in both protein and trace minerals, but the addition of protein was of little benefit without the addition of trace minerals.

Renbarger et al. (1964) supplied trace minerals to an all barley ration, for fattening calves, in the following amounts: Fe, 1000 mg.; Cu, 40 mg.; Co, 3 mg.; Zn, 300 mg.; Mn, 163 mg.; and I, 1 mg. When zinc, cobalt, and iron were added to the ration, the daily gain was 3.19 pounds compared to 2.60 pounds for the control group. When all six trace minerals were added, the daily gain was 3.03 pounds. Feed efficiency was also increased by adding trace minerals. It appeared from these results that adding trace minerals other than zinc, cobalt, and iron would be of no benefit.

Perry et al. (1960), working with fattening lambs, found no advantage from feeding trace minerals. Hubbert et al. (1958) got no added response in cellulose digestibility when each trace mineral was added individually to a deficient medium obtained from the rumen of a steer fed a high corn cob ration. Moody et al. (1958) could attribute no effect on production to trace minerals when dairy cows were fed a ration of high-quality alfalfa hay plus grain mix. Nelson et al. (1956), in a series of experiments, obtained no response when trace minerals were added to the diet of two and three year old stocker cows during winter grazing, weanling heifer calves fed prairie hay free choice, yearling and two year old steers on grass or reproducing cows. Gossett and Riggs (1956) reported no response to trace mineral supplementation of diets for growing beef calves fed poor quality prairie hay. No advantage was obtained by adding trace minerals to rations for fattening steers (Gossett et al. 1962, McCarter et al. 1961, Pope et al. 1959).

Formica et al. (1957) reported that trace minerals somewhat depressed gains of fattening cattle. Plumlee et al. (1953) also reported that the appetite of beef calves was depressed when trace minerals were fed.

AVAILABILITY OF CHELATED TRACE MINERALS

Cardon (1963) stated that for all practical purposes, trace minerals are tied up as mineral-organic complexes. These metal-organic compounds are really chelated complexes. Trace minerals are powerful co-chelators, and the nutritional importance of trace minerals is related to their ability to form these complexes. Animal feeds contain a variety of substances which can act as chelating agents for trace minerals present in the rations. All too often, the complexes, so produced, are insoluble, and its availability for absorption is reduced. Because solubility is necessary for absorption, anything which reduces solubility will, of necessity, reduce availability. Therefore, one may add special chelating agents to the ration which will form soluble complexes with the trace minerals.

Rubin and Princiotto (1963), reporting on some of the chemistry of the chelating phenomenon, defined metal chelates as "cyclic structures of metal atoms and organic ligand formed by donation of electrons from the ligand donor atoms, usually oxygen, nitrogen, or sulfur, to the electron acceptor metal ion. The chemical bond formed in this manner may vary in characteristics from the covalent to the almost completely ionic type. The typically five or six membered ring structure of the chelate may be a labile one with the metal ion in a loose and tenuous equilibrium with the organic ligand or may be of the rigid geometry and tight metal-binding characteristics of the metal porphyrins."

Little work has been done regarding chelated trace minerals in ruminants, however, there has been much interest in the swine and poultry field during the last few years. Kratzer et al. (1959) reported that 150 ppm of zinc must be added to a basal ration containing 25.5 ppm of zinc to get optimum growth and perosis prevention in turkey poults. However, when 227 ppm of Ethylenediaminetetracetic acid (EDTA) was added to the basal ration, the zinc required was reduced to 40 ppm. Scott and Zeigler (1963), working with chicks, reported that when five mg. of zinc was added per kilogram of diet, the addition of 300 mg. of EDTA resulted in markedly improved growth. Green et al. (1961) found that EDTA decreased the fecal excretion of zinc and increased the urinary excretion and the liver storage of zinc in growing pigs. He also found that the addition of 200 ppm of zinc or 450 ppm of EDTA, to a basal ration containing 44 ppm of zinc, produced daily gains of 0.95 pound, 0.81 pound, and 0.57 pound, respectively. According to Green et al. (1962), the addition of EDTA to the ration of pigs significantly improved ($P < .01$) feed efficiency and also improved gain.

Darwish and Kratzer (1963) observed that 45 to 47 percent of orally given EDTA was absorbed in hens. It was found that EDTA was metabolized somewhat as shown by EDTA labeled carbon atoms being found in the carbon dioxide and urine.

Davis et al. (1962) studied the effect of EDTA, in combination with zinc, manganese, copper, and iron in rations for chicks. It was found that the addition of EDTA increased gain on a low zinc diet. It was also found that the highest level of zinc plus EDTA gave the same results as that level of zinc without EDTA, indicating that EDTA itself is not growth stimulating. Davis also obtained an increase in growth, with the addition of

EDTA to the diet, when manganese or copper were deficient in the ration. It was also shown in the work with manganese that EDTA itself does not promote growth. No response was obtained when EDTA was added to an iron deficient ration. Rubin and Princiotto (1963) reported that there is some absorption of the Fe EDTA complex. They also found that chelating cobalt with EDTA provided cobalt in a non-toxic biologically available form. Miller et al. (1963) reported that there was no increase in transfer of iron from chelates as measured by placental and mammary transfer with sows.

Other compounds are also used as chelating agents. Miles and Watts (1963) found that 400 grams of EDDHA (ethylenediamine di (o-hydroxy-phenylacetic acid) tends to promote rapid growth. When 1200 grams of EDDHA was added, growth was depressed.

The property of a chelating agent that may give it the ability to make trace minerals more available is the stability constant of the chelating agent. Kratzer and Vohra (1963) reported that a stability constant between 12 and 17 was the most favorable for growth promoting activity of chelates on zinc. Vohra and Kratzer (1964) found that EDTA and hydroxyethylethylene-diaminetriacetic acid (HEDTA) stability constants of 14.5 and 16.5 improved the availability of zinc, in turkey poults, while 1,2-Diaminocyclohexanete-traacetic acid (CDTA) and Diethylenetriaminepentaacetic acid (DTPA), stability constants of 18 or over were not suitable for improving the availability of zinc. According to the same workers, the mechanism involved may be that the chelating agent has a stronger stability constant for the metal than the metal binding substance in the food. The mineral would then be complexed with the chelating agent in the gastrointestinal tract. After absorption the metal might be available for specific body functions if it can be removed from the chelating agent. This means that the various systems in which the metal is required for proper functions (enzymes) should have a higher stability constant for the metal than the chelating agent. Thus the reason that CDTA and DTPA were not acceptable is that there stability constant was too high for the metal to be removed by the body. It was speculated here that chelating agents with stability constants below 13 may not be able to release zinc from its bound form, and a compound with a stability constant above 16.5 chelates the metal too strongly.

PROCEDURE

These experiments were conducted at the Nutrition Center located one mile west of the Montana State College campus, Bozeman, Montana. The experimental area consisted of eight pens, four separated but adjoining pens on each side of a feeding alley. Fenceline bunks were used with salt boxes located in the end of the bunk for each lot. There was one electrically heated watering cup per two lots. A board fence completely surrounded the feeding area. The surface of the feeding pens was covered with asphalt.

Upon arrival at the Nutrition Center, the calves were branded with the college brand and vaccinated for Blackleg and Infectious Bovine Rhinotracheaitis (Red Nose).

The calves were hand fed twice daily. The feed was weighed and mixed in large cans and spread in the bunks. The same concentrate mixture, 80 percent barley and 20 percent beet pulp was fed to all lots. The grass hay fed was of approximately the same composition each year. Straw was used as bedding and it was added to the back half of the pen as needed. The front portion, next to the feed bunk, was kept as clean as possible.

Initial and final weights of heifers were taken after a 15 hour overnight shrink. The calves were individually weighed every 28 days throughout the feeding trial. All of the calves were ear-tagged for identification purposes.

Experiment I. Effect of Trace Mineral Supplements on the Performance of Fattening Heifer Calves.

Experiment I was designed to evaluate the addition of three commercial trace mineral mixtures to fattening rations fed heifer calves. The trace minerals added were: cobalt, copper, iron, manganese, iodine, and zinc. The experimental animals used in the experiment consisted of 32 head of Hereford heifer calves weighing approximately 515 pounds. The calves were bred and raised by the Montana Agricultural Experiment Station, Red Bluff Ranch, Norris, Montana. The calves were weaned October 9, 1962, and trucked to the Nutrition Center on the following day. The calves were grouped into four pens and fed a wintering ration of native hay and grain until the experiment began.

The 32 head of heifers were allotted to their respective lots prior to the start of the experiment. The heifers were stratified according to individual weights and randomly assigned to one of four lots. Each lot was randomly assigned to one of the four treatments.

All of the calves received the same basal ration, the only difference being the kind and amount of trace minerals in the protein supplement. The trace minerals added to each were as follows: Lot 5, received trace minerals; Lot 6, no trace minerals; Lot 7, chelated trace mineral; Lot 8, trace minerals plus high zinc. The design of the experiment, and the composition of the protein supplements with trace mineral additions are shown in Table I. The composition and cost of trace mineral supplements are shown in Appendix Table IV.

The protein supplement pellet was calculated to contain 20 percent