Effect of supplemental manganese and biotin on growing-finishing pigs
by Darlene Sue Bechtold

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

Abstract:
Three trials were conducted to study the effect of supplemental manganese on growing and finishing pigs. The pigs were fed 0, 27.5, 41.25 and 55.0 mg/kg of supplemental manganese in one trial; 27.5, 41.25 and 55.0 mg/kg of supplemental manganese in the second trial; and 27.5 or 55.0 mg/kg of supplemental manganese in combination with 0 to 50 µg of supplemental biotin. In the first trial, no differences were found in average daily gain, feed consumption, feed efficiency, carcass data or blood and bone tissue levels of manganese among groups on one of four levels of manganese. In the second trial, average daily gain, feed consumption and feed efficiency were nearly the same for pigs on all three levels of supplemental manganese.

In the third trial, the level of manganese did not affect average daily gain, feed consumption or feed efficiency. However, there was a sex x biotin interaction for barrows on 50 µg of supplemental biotin compared to barrows on 0 µg of supplemental biotin. Barrows on both levels of supplemental manganese and biotin gained better than gilts on both levels of supplemental manganese and biotin.

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Date May 28, 1976

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by

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A thesis submitted in partial fulfillment
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of

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June, 1976

ACKNOWLEDGMENTS

I wish to thank the following individuals for their contributions in completing my thesis and graduate program:

Dr. C. W. Newman for his assistance with this thesis and my graduate program; Dr. Frank Munshower for his advice and the use of his laboratory for the tissue analyses; Dr. Stephen Chapman for his advice as a member of my graduate committee; Dennis Neuman for his help with the chemical analysis; Kathy Hocevar for technical assistance; Dr. Erwin Smith for his help with the statistical analysis; Don McCarl of MSU and Delbert Elliott, Alphonse Prevel and Lester Schied of the USRLES for care of the pigs; Frankie Larson for typing the thesis; Shirley, Nancy and Dana, the staff of the Nutrition Center, for their technical assistance; my husband and friends for their patience and support.

TABLE OF CONTENTS

	Page
VITA	ii
ACKNOWLEDGMENTS	iii
LIST OF TABLES	v
LIST OF APPENDIX TABLES	vii
ABSTRACT	viii
INTRODUCTION	1
LITERATURE REVIEW	2
Monogastrics	2
Ruminants	4
Tissue concentration of manganese	6
Metabolic role	7
Absorption and excretion	8
Interactions with other nutrients	8
Deficiency symptoms and requirements	9
PROCEDURE	13
Bozeman Trial	13
Miles City Trial 1	15
Miles City Trial 2	15
RESULTS	17
Bozeman Trial	17
Miles City Trial 1	18
Miles City Trial 2	18
DISCUSSION	30
SUMMARY	31
LITERATURE CITED	32
APPENDIX	35

LIST OF TABLES

Table		Page
1	PROXIMATE ANALYSIS, CALCIUM, PHOSPHORUS AND MANGANESE IN FINISHER DIETS FED PIGS IN BOZEMAN TRIAL.	20
2	COMPOSITION OF GROWER AND FINISHER DIETS USED IN BOZEMAN TRIAL.	21
3	PERFORMANCE OF PIGS ON FOUR LEVELS OF MANGANESE DURING GROWING-FINISHING PERIOD FROM 25 kg TO 98.5 kg IN BOZEMAN TRIAL	22
4	CARCASS DATA FROM PIGS ON FOUR LEVELS OF MANGANESE DURING GROWING-FINISHING PERIOD FROM 25 kg TO 98.5 kg IN BOZEMAN TRIAL.	23
5	RESULTS OF ANALYSIS OF BLOOD SERUM, RIB AND METATARSAL FROM PIGS ON FOUR LEVELS OF MANGANESE IN BOZEMAN TRIAL . .	24
6	COMPOSITION OF GROWING AND FINISHING DIETS USED IN MILES CITY TRIAL 1	24
7	RESULTS OF ANALYSIS OF BLOOD SERUM, RIB AND METATARSAL FROM PIGS ON FOUR LEVELS OF MANGANESE IN THE BOZEMAN TRIAL.	25
8	PROXIMATE ANALYSIS, CALCIUM, PHOSPHORUS AND MANGANESE CONTENT OF GROWER AND FINISHER DIETS FED TO PIGS IN MILES CITY TRIALS 1 AND 2.	26
9	PERFORMANCE OF PIGS ON THREE LEVELS OF SUPPLEMENTAL MANGANESE DURING GROWING AND FINISHING PERIOD FROM 19.6 kg TO 98.7 kg IN MILES CITY TRIAL 1	27
10	PERFORMANCE OF BARROWS COMPARED TO GILTS ON THREE LEVELS OF SUPPLEMENTAL MANGANESE DURING GROWING-FINISHING PERIOD FROM 19.6 kg TO 98.7 kg IN MILES CITY TRIAL 1.	27
11	PERFORMANCE OF BARROWS ON ALL THREE LEVELS OF SUPPLEMENTAL MANGANESE COMPARED TO GILTS ON ALL THREE LEVELS OF SUPPLEMENTAL MANGANESE DURING GROWING-FINISHING PERIOD FROM 19.6 kg TO 98.7 kg IN MILES CITY TRIAL 1.	27

Table | Page

12 PERFORMANCE OF PIGS ON TWO LEVELS OF MANGANESE WITH OR WITHOUT SUPPLEMENTAL BIOTIN DURING GROWING-FINISHING PERIOD FROM 18 kg TO 97 kg IN MILES CITY TRIAL 2 28

13 PERFORMANCE OF BARROWS COMPARED TO GILTS ON TWO LEVELS OF MANGANESE DURING THE GROWING-FINISHING PERIOD FROM 18 kg TO 97 kg IN MILES CITY TRIAL 2 28

14 PERFORMANCE OF BARROWS COMPARED TO GILTS WITH OR WITHOUT SUPPLEMENTAL BIOTIN DURING THE GROWING-FINISHING PERIOD FROM 18 kg TO 97 kg IN MILES CITY TRIAL 2 28

15 PERFORMANCE OF ALL BARROWS COMPARED TO ALL GILTS DURING GROWING-FINISH PERIOD FROM 18 kg TO 97 kg IN MILES CITY TRIAL 2. 29

LIST OF APPENDIX TABLES

Table		Page
16	LEAST SQUARES ANALYSIS OF VARIANCE OF AVERAGE DAILY GAIN DATA FROM PIGS ON THE BOZEMAN TRIAL	36
17	LEAST SQUARES ANALYSIS OF VARIANCE OF CARCASS DATA FROM PIGS ON THE BOZEMAN TRIAL	37
18	LEAST SQUARES ANALYSIS OF VARIANCE OF BLOOD SERUM, RIB, AND METATARSAL DATA FROM PIGS ON FOUR LEVELS OF MANGANESE IN THE BOZEMAN TRIAL.	38
19	ANALYSIS OF VARIANCE OF AVERAGE DAILY GAIN DATA FROM PIGS ON THREE LEVELS OF SUPPLEMENTAL MANGANESE IN MILES CITY TRIAL 1	39
20	ANALYSIS OF VARIANCE OF FEED EFFICIENCY AND FEED CONSUMPTION DATA FROM PIGS ON THREE LEVELS OF SUPPLEMENTAL MANGANESE IN MILES CITY TRIAL 1	39
21	LEAST SQUARES ANALYSIS OF VARIANCE OF AVERAGE DAILY GAIN DATA FROM PIGS IN MILES CITY TRIAL 2.	40
22	ANALYSIS OF VARIANCE OF FEED CONSUMPTION DATA FROM PIGS IN MILES CITY TRIAL 2	40

ABSTRACT

Three trials were conducted to study the effect of supplemental manganese on growing and finishing pigs. The pigs were fed 0, 27.5, 41.25 and 55.0 mg/kg of supplemental manganese in one trial; 27.5, 41.25 and 55.0 mg/kg of supplemental manganese in the second trial; and 27.5 or 55.0 mg/kg of supplemental manganese in combination with 0 to 50 µg of supplemental biotin. In the first trial, no differences were found in average daily gain, feed consumption, feed efficiency, carcass data or blood and bone tissue levels of manganese among groups on one of four levels of manganese. In the second trial, average daily gain, feed consumption and feed efficiency were nearly the same for pigs on all three levels of supplemental manganese. In the third trial, the level of manganese did not affect average daily gain, feed consumption or feed efficiency. However, there was a sex x biotin interaction for barrows on 50 µg of supplemental biotin compared to barrows on 0 µg of supplemental biotin. Barrows on both levels of supplemental manganese and biotin gained better than gilts on both levels of supplemental manganese and biotin.

INTRODUCTION

Manganese was established as a constant component of plant and animal tissues in the 1920's. McHargue (1923) demonstrated that manganese was necessary for the growth of plants and microorganisms. Kemmerer (1930), Waddell (1931) and Orent and McCollum (1931) showed that manganese was required for normal growth and ovarian activity in mice and rats and was necessary to prevent testicular degeneration in rats. Wilgus (1937) found that manganese supplementation could prevent perosis in chicks and Lyons (1937) showed manganese supplementation could prevent nutritional chondrodystrophy in the chick embryo. Later workers found that pigs on low manganese levels became lame, suffered bone deformities and had reproductive difficulties. Additional manganese could prevent these symptoms but not cure them. Similar results were obtained with goats and cattle.

Manganese is known to activate several enzymes <u>in vitro</u> that are activated by other bivalent ions. It is important in cholesterol synthesis, glucose utilization, normal reproduction, cartilage and bone formation and the metalloprotein, pyruvate carboxylase.

Pigs at the Montana Agricultural Experiment Station on 0 or 27.5 mg/kg supplemental manganese have exhibited lameness and stiffness which could not be explained on the basis of diet or factors being examined. Therefore, this project was undertaken to determine whether manganese was deficient or adequate in barley-soybean meal diets commonly fed to pigs in Montana.

LITERATURE REVIEW

Monogastrics. Early efforts to determine manganese requirements with animals on purified diets were unsuccessful since the diets were so deficient in other nutrients the animals usually failed to survive. Then Kemmerer (1931) and Waddell (1931) showed that manganese was required for growth and normal ovarian activity in mice and rats. Orent and McCollum (1931) found that the rat required manganese to prevent testicular degeneration. In 1937, Wilgus demonstrated that manganese could prevent perosis in chicks and Lyons (1937) showed it would prevent chondrodystrophy in the chick embryo.

Miller et al., (1940) suggested that natural diets for swine might be deficient in manganese. They found that at 68 kg live weight, half of a group of 60 hogs on 11 to 14 mg/kg of manganese developed lameness. Added manganese which raised diet levels to 50 to 60 mg/kg prevented but could not cure the lameness. Johnson (1943, 1944) reported that pigs fed both semi-purified and natural diets low in manganese showed satisfactory gains with no evidence of lameness. In 1950, Grummer et al. found that pigs on a diet of natural feedstuffs containing 52 mg/kg manganese gained significantly more than pigs on a basal diet supplying 12 mg/kg manganese. Gilts from the lower manganese level group required more services per conception and farrowed fewer pigs per litter. Plumlee et al., (1956) conducted several experiments that showed rate of gain and feed efficiency were the same for pigs on semi-purified diets supplying from 0.5 to

40 mg/kg manganese during the growing period from initial weights of 4.26 to 19.5 kg and to final weights between 83.9 and 111.6 kg. Prolonged feeding of diets containing 0.5 to 3.5 mg/kg manganese resulted in tissue depletion of two to ten times that of controls receiving 40 mg/kg manganese. Female pigs fed from a weight of 4.26 kg at three weeks of age through growth, gestation and lactation periods on diets containing either 0.5 mg/kg or 40 mg/kg manganese showed several deficiency symptoms at the low level. Deficient gilts had significantly greater backfat thickness at an average weight of 74.4 kg. There was reduced skeletal growth accompanied by muscular or skeletal weakness. Irregular estrus cycles, absence of estrus or absence of marked signs of estrus were observed in deficient gilts. There was evidence of resorption of some fetuses and birth of small pigs which could not stand or walk normally. The baby pigs' tissues contained only about 33% as much total manganese as tissues of control pigs. Deficient gilts had poor udder development and little milk production and secretion with colostrum and milk which contained 33% less manganese than similar samples from a control gilt. First generation gilts showed a reduction in tissue manganese of from 10 to 20% of the controls. Leibholz and associates (1962) concluded that 0.4 mg/kg manganese in the diet is sufficient to meet the baby pigs' needs; therefore, natural diets should supply sufficient manganese for normal growth. Svajgr et al., (1969) reported that average daily gain

was significantly reduced when 50 mg/kg manganese was added to a basal diet containing 8.1 mg/kg manganese. Everson (1969) reported that in studies with guinea pigs on a control diet with 125 mg/kg manganese and a deficient diet with 2 to 3 mg/kg manganese, the deficient dams had offspring that were ataxic at birth, stillborn, or often died within three to four days. There was a shortening of the long bones, enlargement and malformation of joints, shortening and doming of the skull, deformed or missing ribs and anterior-posterior flattening of the chest. Where abnormal head movements were observed, either unilateral or bilateral otolith defects were present. Postnatal supplementation of manganese failed to reverse the symptoms. In stillborn young guinea pigs, there was hypoplasia of the pancreas, reduced islet population and increased islet size. In manganese-deficient young guinea pigs, dietary supplementation for two months increased the number of islets and the beta cells were more intensely granulated. However, the islets remained large with a greater number of alpha cells.

Ruminants. Manganese deficiencies have been experimentally produced in grazing animals. Bentley and Phillips (1951) reported that cows on a manganese-deficient diet had delayed estrus and conception and weak-legged offspring. Anke and Groppel (1969) found that calves on 8 mg/kg manganese in milk-maize diet developed a nervous tremor of the tongue, general ataxia and a trembling of

muscles. Later, they noted an excrescence on the front tarsal joint and a stiff, steeper position of the front legs. Rojas et al., (1965) tested Hereford cows on low manganese diets and found their offspring had neonatal deformities with reduced breaking strength and length of the humerus and lower levels of manganese in bones, liver, kidney, blood and gonads. Anke and Groppel (1969) discussed studies with female goats during 1966 to 1969. Controls received 100 mg/kg manganese and another group received 20 mg/kg manganese the first year and 6 mg/kg manganese the following year. There was no change in growth. The low manganese goats came into estrus later, the signs of estrus were weak, and more inseminations were needed for pregnancy. Later, 23% of the low manganese goats aborted in the third to fifth month compared to no abortions in the control group. The proportion of male to female kids were 1:1.5 in the control group and 1:2.3 in the low manganese group. Similar results were obtained in a cattle trial in which manganese-deficient dams produced a sex ratio of 1:1.3 compared to 1:1 in controls. In the goats, birth weights were lower and mortality rates higher in manganese deficient goats. Some of the females and kids developed bony excrescences on the front tarsal joint. Generally, deficient kids had less manganese in the liver and femur as well as in the total body. Anke and Groppel (1969) and Lassiter and Morton (1969) found that ash concentration in the femur was lowered and the calcium and phosphorus

percentages were greatly reduced in older animals on low manganese. Lassiter and Morton (1969) also reported that lambs receiving a purified diet containing 1 mg/kg manganese over a five month period were compared to a group with the same diet supplemented with 29 mg/kg manganese. The low manganese lambs had tibias which were lighter, lower in volume, shorter, lower in breaking strength and lower in ash, calcium, and manganese than controls.

Tissue concentration of manganese. Tissue concentrations of manganese are highly characteristic for particular organs and body fluids. Total body manganese varies little within or among species or with age. It is generally higher in mitochondria-rich tissue and pigmented tissue. The bones, liver, kidney, pancreas and pituitary gland are highest with from 1 to 3 mg/kg on a fresh basis. Skeletal muscle is lowest at 0.1 to 0.2 mg/kg. Milk from most species is relatively low but varies considerably with species and dietary intake. Skin and hair concentrations vary with the individual, its color and dietary intake. Dark hair, feathers and wool contain higher concentrations of manganese than lighter coverings even when on the same animal. Concentrations in the liver, hair and bones reflect the dietary intake of the animals. Most newborn animals have no liver reserves of manganese and the liver has a limited storage capacity. Regardless of dietary factors, the body proportions of manganese are relatively stable with about 25% in the skeleton, 25% in the skin

and feathers, 25% in the muscle, 10% in the liver, kidney, ovary and oviducts, and the remainder distributed in other tissues such as the brain, pituitary gland and pancreas. Reported values for blood serum vary widely, although all are low. They range from less than 10 µg/liter to 24 µg/liter.

Metabolic role. In vitro work has shown that manganese activates arginase, cystine cisulfhydrase, thiaminase, carnosinase, deoyribonuclease, intestinal prolinease, enolase and glycyl-L-leucine dipetidase as do several other bivalent ions. The metalloprotein pyruvate carboxylase, which has a fixed amount of manganese per molecule, aids transcarboxylation in the pyruvate carboxylase reaction. Manganese in blood serum and liver is almost all protein bound. Cotzias (1962) discussed evidence that manganese is required for oxidative phosphorylation. Manganese also appears to be important in fatty acid synthesis. Jukes (1940) found that manganese and choline interact to reduce bone and liver fat in rats. Plumlee et al., (1956) reported manganese supplementation reduced backfat deposition in pigs. Curran and Clute (1953) concluded that manganese is a co-factor in acetate incorporation into cholesterol. Leach et al., (1969) identified two important reactions in the chondroitin sulfate synthesis which requires manganese. Although important to reproduction, the function of manganese in reproductive processes is unclear.

Everson and Schrader (1968) showed a requirement for manganese in glucose utilization. In deficient guinea pigs, pancreatic abnormalities were noted along with reduced glucose utilization which could be reversed by manganese supplementation.

Absorption and excretion. Cotzias and associates (1962) concluded that there is a specific pathway in the body for manganese alone. Its absorption mechanism from the intestine is unknown but it is believed to be an active transport similar to the pathway for iron. Excretion is primarily through the bile with lesser amounts excreted through pancreatic juices when the bilary route is blocked or manganese overloading occurs. Auxilary routes also exist through the duodenum, jejunum and terminal ileum. Almost no excretion occurs normally via the urine. It is generally thought that the relative stability of manganese concentrations in tissue is due to controlled excretion rather than controlled absorption.

Interactions with other nutrients. Lassiter and associates (1969) found that high calcium levels in the diet affected retention and absorption of manganese, whereas high phosphorus levels impaired absorption but not retention. Matrone et al.,(1959) found that the depressing effect on hemoglobin formation of baby pigs by 2000 mg/kg manganese could be nullified by supplementing 400 mg/kg iron in the diet. Hogan et al., (1941) found that perosis occurred in chickens when adequate manganese was available and that choline could prevent

this perosis. Perla and Sandberg (1939) found that the effects of excessive thiamine on maternal ability could be reversed by feeding 2 mg of manganese per rat per day. Jukes and Welch (1942) found that choline analogs were effective in replacing choline in the diet. Amdur et al., (1946) found manganese and choline prevented deposition of excess fat in rat liver. This effect was greater on a low choline diet. Manganese and choline supplementation reduced the percent fat in fresh bone.

Deficiency symptoms and requirements. In most animals, the deficiency symptoms are similar. Deficient rats show retarded bone growth with shortening and bowing of the forelegs. The offspring of deficient dams exhibit shortening of the tibia, ulna and fibula; marked epiphyseal dysplasia at the proximal end of the tibia; shortening and doming of the skull; and ossification of the inner ear. Three stages of deficiency have been identified in the female rat. In the least severe stage, the young are viable with some or all displaying ataxia. In a more severe stage, the young are born weak or dead. In the most severe stage, estrus cycles are irregular or absent. No mating occurs and sterility results. Hurley et al., (1958) demonstrated that irreversible ataxia in young rats resulted when there was a manganese deficiency during pregnancy. In the rat, the fifteenth and sixteenth days were critical. Manganese supplementation begun at that time decreased or prevented the symptoms; whereas

beginning supplementation on the eigteenth day was ineffective in preventing ataxia in the offspring. Levels of 1 to 4 mg/day or 20 to 80 mg/kg of the dry diet appear to be adequate for normal growth and reproduction in rats. Rabbits and mice appear to have similar requirements.

In growing chicks, poults and ducklings, perosis results from a deficiency of manganese. Perosis is characterized by enlargement and malformation of the tibiometratarsal joint, twisting and bending of the tibia and tarsometatarsus, shortening and thickening of the long bones, and the slipping of the gastrocnemius tendon from its condyles. In chick embryos, the disease nutritional chondrodystrophy occurs. Its symptoms include shortened and thickened legs and wings, "parrot" beak, a globular contour of the head due to an anterior bulging of the skull and a high mortality rate. A recommended dietary level of 50 mg/kg is adequate for chickens. Atkinson and co-workers (1967) suggested that 54 to 108 mg/kg may be needed for satisfactory performance in turkey hens. It has also been shown that heavier breeds of chickens have higher requirements for manganese than lighter breeds. However, no increased requirement has been associated with a higher rate of egg production.

In pigs, manganese deficiency produces stiffness, lameness, enlarged hock joints, crooked and shortened legs, depressed estrus, an increased number of services per conception, evidence of fetal

death and resorption, weak newborns, fewer piglets per litter farrowed and poor udder development and lactation. Growth requirements appear considerably less than reproductive needs. Satisfactory gain and feed efficiency were obtained with as little as 0.5 mg/kg. Gilts in this low level later showed impaired reproductive functions. Several authors concluded that natural feedstuffs in pig diets usually contain 20 mg/kg manganese, the level recommended by NRC for pig diets. Plumlee et al., (1956) found that 40 mg/kg supplementation of manganese could prevent but not cure the deficiency symptoms in deficient female pigs.

Symptoms of experimentally produced manganese deficiency in cattle are leg deformities with "overknuckling", delayed estrus and poor fertility; in sheep, joint pain, poor locomotion and impaired balance; in goats, tarsal joint excrescence, ataxia, delayed estrus, lowered fertility, higher abortion rates and increased mortality rates.

Minimum daily requirements are not precisely known for sheep, cattle, or goats. Apparently no work has been done with sheep. Requirements for body growth appear much lower than requirements for fertility and normal bone development in ruminants. Bentley and Phillips (1951) reported that 10 mg/kg was adequate for growing heifers but marginal for maximal reproduction in dairy cows. They found that higher levels of manganese did not improve growth in heifers or milk production in cows but animals on the lower levels exhibited estrus

later, were slower to conceive and had more calves with weak legs and pasterns. Anke and Groppel (1969) produced ataxic and joint abnormalities in calves fed a milk-maize diet supplying 8 mg/kg manganese. Rojas et al., (1965) found that Hereford cows required more than 10 mg/kg manganese for optimum fertility. Anke and Groppel (1969) concluded that growth of female goats on diets containing 20 mg/kg manganese the first year and 6 mg/kg manganese the following year were comparable to growth of female goats on a diet supplying 100 mg/kg manganese. However, the goats on the lower levels showed depressed estrus; 23% more abortions, kids with significantly lower birth weights and a higher male:female ratio in the kids.

PROCEDURE

Bozeman Trial

Forty weanling pigs averaging 25 kg were stratified in four comparable groups of ten pigs each on the basis of initial weight, sex and breed. Groups were randomly assigned to one of four diet treatments, 0, 27.5, 41.25 or 55.0 mg/kg supplemental manganese. Diets were prepared in meal form with barley and soybean meal fortified with minerals and vitamins. Manganese sulfate provided the source of manganese (table 1). Proximate analysis (A.O.A.C., 1970) and manganese levels were determined by a modification of the procedures of Ross and Gonzalez (1974), Muzzarelli and Rocchetti (1975) and Paggenkopf, Neuman and Woodriff (1972).

The pigs were fed ad libitum in dirt lots with adequate shelter and water. Pigs were weighed initially and when changed to finishing diet (approximately 50 kg) and were removed individually at 98.5±2.3 kg for slaughter. Average daily gain, average daily feed and average feed/gain ratios were calculated.

Carcass weight, carcass length, average backfat thickness, loin eye area and weight of ham, loin, Boston butt and picnic shoulder were collected for each carcass. Percentages of ham and carcass yield were calculated on a live weight basis and lean cut percentages were calculated on the basis of chilled carcass weight. Carcass length, average backfat and loin eye area were adjusted to 99.8 kg using standard procedures of the National Association of Swine Records.

Prior to slaughter, blood was drawn from the vena cava of each pig and allowed to coagulate at room temperature. After centrifugation, the serum portion was stored at -15.6° C until analysis for total manganese by atomic absorption spectrophtometry using a modified procedure of Ross and Gonzalez (1974) and Muzzarelli and Rocchetti (1975). Five microliters of serum were diluted 1:2 with 0.1% solution of Triton X-406 and five microliters of that solution was aspirated into the graphite atomizer.

Metatarsal bones from the rear foot and a rib section were removed, cleaned and dried overnight in a forced-air oven at 100° C. Length and width of the metatarsals were measured with a micrometer. The dried bones were broken into small pieces and dried overnight at 100° C in a forced-air oven. The fat was extracted from the bones with anhydrous ether. The bone samples were digested in 3:2 HNO_3:$HClO_4$ mixture and brought to 50 ml in volumetric flasks. The samples were analyzed for manganese by atomic absorption spectrophotometry (Paggenkopf et al., 1972).

Data were analyzed by analysis of variance (Harvey, 1960) and differences between means tested by the Newman-Keuls multiple range test (Snedecor and Cochran, 1967) where significance was detected. Feed consumption and feed efficiency data were not analyzed as pigs were group fed and treatments not replicated.

Miles City Trial 1

Five hundred twenty-one pigs averaging 18.5 kg were allotted in equal numbers to three treatment groups on the basis of initial weight, sex and breed. Three barley-soybean meal diets fortified with minerals and vitamins and containing manganese sulfate to supply 27.5, 41.25 or 55.0 mg/kg of supplemental manganese (table 2) were prepared in meal form and fed ad libitum in four replications. Equal groups of pigs were randomly assigned to one of these diets. Proximate analysis (A.O.A.C., 1970) were determined on all diets.

Pigs were fed in open dirt lots having adequate water available and concrete floored wooden sheds for shelter. The pigs were weighed as in the Bozeman trial and removed at approximately 98.7±2.3 kg for slaughter. Average daily gain, average daily feed and average feed/gain ratios were calculated.

Average daily gains were analyzed by the same methods as in the Bozeman trial. Feed consumption and feed efficiency data obtained from replications were analyzed by analysis of variance (Snedecor and Cochran, 1967).

Miles City Trial 2

Two hundred thirty-three pigs averaging 18 kg were stratified in equal numbers to four groups according to initial weight, sex and breed. Four barley-soybean meal diets fortified with minerals and vitamins were prepared with manganese sulfate to supply 27.5 or 55.0

mg/kg of supplemental manganese and with 50 µg or 0 µg of supplemental biotin (table 3). Groups of pigs were assigned randomly to one of four diet combinations in six replications of each diet.

Otherwise, the pigs were managed and data collected and analyzed in the same manner as in Miles City Trial 1.

RESULTS

Bozeman Trial

Chemical analyses of diets are shown in table 4. The basal diet (No. 1) in which no supplemental manganese was added contained 18 mg/kg manganese. Analysis of the remaining diets were in general agreement with the added level of manganese plus that contained in the basal diet. No major differences existed in protein or other proximate components.

There were no significant differences in average daily gains due to level of manganese (table 5) (Appendix table 16). Although the data could not be analyzed statistically, the pigs fed the basal diet appeared to eat more feed than those fed manganese supplemented diet 2. The 55 mg of manganese per kg of diet appeared to depress feed intake; however, as a result the feed efficiency was improved since gains were similar between treatment groups.

The carcass data (table 6) (Appendix table 17) tended to show an improvement in carcass leanness with pigs fed the higher level of manganese but differences were not statistically significant.

There were no significant differences in the manganese content of blood serum (table 7) (Appendix table 18) although serum from pigs fed the basal diet appeared to have the greatest concentration of manganese. Supplemental manganese level had no effect on manganese concentration in metatarsal bones or in the size of bones. The two high levels of supplemental manganese appeared to increase the concentration

of manganese in the ribs; however, the difference was not statistically significant.

Miles City Trial 1

Chemical analyses of grower-finisher diets are shown in table 8. The amounts of manganese found in the diets are in general agreement with levels in the Bozeman trial except Finisher 3 seems higher than others at the 55 mg/kg level. No major difference existed in protein or other proximate components.

Average daily gains showed no significant differences due to level of manganese (table 9) (Appendix table 19). There were no significant differences in average feed consumption or average feed efficiency due to level of supplemental manganese. However, it appeared that feed efficiency was best at the 27.5 mg/kg of supplemental manganese. Where barrows were separated from gilts and each group compared, there were no differences among averages for barrows or gilts on any of the three levels of supplemental manganese (table 10). When barrows on all three levels of supplemental manganese are compared to gilts on all three levels of supplemental manganese, the barrows gained ($P<.01$) better than gilts.

Miles City Trial 2

Chemical analyses of grower-finisher diets are shown in table 8. Manganese levels appear lower compared to Bozeman trial and Miles City trial 1 results. Protein and other proximate components did not

differ markedly.

Average daily gain did not appear to be affected by either the level of biotin or level of supplemental manganese (table 12) (Appendix table 21). Average feed consumption and average feed efficiency were not affected by dietary treatments. Barrows on both levels of manganese were essentially the same as were gilts on both levels of manganese (table 13). However, barrows on 50 µg of supplemental biotin gained less than barrows ($P<.10$) with no supplemental biotin. Whereas, gilts gained about the same on either 50 µg of supplemental biotin or no supplemental biotin. This is indicative of a sex x biotin interaction. Again, when all barrows are compared to all gilts on either of the two levels of supplemental manganese with 50 µg of supplemental biotin or without supplemental biotin, the barrows gained significantly more than the gilts.

TABLE 1. COMPOSITION OF BASAL GROWER AND FINISHER DIETS USED IN BOZEMAN TRIAL[a]

Feedstuff	Grower %	Finisher %
Barley	81.80	88.85
Soybean meal	15.00	8.60
Deflourinated rock phosphate	1.50	1.10
Limestone	0.50	0.60
Salt	0.50	0.50
Vitamin premix[b]	0.40	0.25
Trace mineral premix[c]	0.05	0.05
Antibiotic[d]	0.25	0.05

[a] Three otherwise identical diets were formulated to contain 27.5, 41.25 and 55.0 mg/kg supplemental manganese using manganese sulfate.

[b] Contains the following per kg: 1,102,312 I.U. vitamin A, 220,462 I.U. vitamin D_3, 2,205 I.U. vitamin E, 992 mg vitamin K, 8.8 mg vitamin B_{12}, 1,543 mg riboflavin, 8,818 mg niacin, 4,409 mg pantothenic acid, and 220,462 mg choline.

[c] Contained the following per kg: 200 g zinc, 100 g iron, 11 g copper, 1 g cobalt and 1.5 g iodine.

[d] Antibiotic in growing diets contained 44.1 g chlortetracycline, 44.1 g sulfamethazine and 22 g penicillin per kg and the antibiotic in finishing diet contained 110 g chlortetracycline per kg.

TABLE 2. COMPOSITION OF BASAL GROWING AND FINISHING DIETS USED IN MILES CITY TRIAL 1[a]

Feedstuff	Grower %	Finisher %
Barley	82.00	88.88
Soybean meal	15.00	8.6
Defluorinated rock phosphate	1.50	1.1
Limestone	0.50	0.6
Salt	0.50	0.5
Vitamin premix[b]	0.40	0.25
Trace mineral premix[c]	0.05	0.05
Antibiotic[d]	0.05	0.02

[a] Two otherwise identical diets were formulated to contain 41.25 and 55.0 mg/kg supplemental manganese using manganese sulfate.

[b] Contains the following per kg: 1,102, 312 I.U. vitamin A, 220,462 I.U. vitamin D_3, 2,205 I.U. vitamin E, 992 mg vitamin K, 8.8 mg vitamin B_{12}, 1,543 mg riboflavin, 8,818 mg niacin, 4,409 mg pantothenic acid, and 220,462 mg choline.

[c] Contains the following per kg: 200 g zinc, 100 g iron, 11 g copper, 55 g manganese, 1 g cobalt, and 1.5 g iodine.

[d] Contained 110 g oxytetracycline per kg.

TABLE 3. COMPOSITION OF GROWING AND FINISHING DIETS USED IN MILES CITY TRIAL 2[a]

	Grower		Finisher	
Biotin, µg	0	50	0	50
Feedstuff	%	%	%	%
Barley	82.00	81.95	88.88	88.83
Soybean meal	15.00	15.00	8.60	8.60
Defluorinated rock phosphate	1.50	1.50	1.10	1.10
Limestone	0.50	0.50	0.60	0.60
Salt	0.50	0.50	0.50	0.50
Vitamin premix[b]	0.40	0.40	0.25	0.25
Trace mineral premix[c]	0.05	0.05	0.05	0.05
Biotin premix	--	0.05	--	0.05
Antibiotic[d]	0.05	0.05	0.02	0.02

[a] One otherwise identical diet was formulated to contain 55.0 mg/kg supplemental manganese using manganese sulfate at each level of biotin.

[b] Contained the following per kg: 1,102, 312 I.U. vitamin A, 220,462 I.U. vitamin D_3, 2,205 I.U. vitamin E, 992 mg vitamin K, 8.8 mg vitamin B_{12}, 1,543 mg riboflavin, 8.818 mg niacin, 4,409 mg pantothenic acid and 220,462 mg choline.

[c] Contained the following per kg: 200 g zinc, 100 g iron, 11 g copper, 55 g manganese, 1 g cobalt and 1.5 g iodine.

[d] Contained 110 g oxytetracycline per kg.

TABLE 4. PROXIMATE ANALYSIS, CALCIUM, PHOSPHORUS AND MANGANESE IN FINISHER DIETS FED PIGS IN THE BOZEMAN TRIAL

Diet No.	Added Mn level mg/kg	Moisture %	Protein %	Ash %	Ether extract %	Crud fiber %	NFE %	Ca %	P %	Mn mg/kg
1 (Basal)	0	6.8	13.2	4.5	1.9	4.0	69.6	0.47	0.53	18.0
2	27.5	6.6	13.7	5.0	2.0	4.4	68.3	0.56	0.59	42.0
3	41.25	5.9	13.6	5.1	1.8	4.0	69.6	0.60	0.59	57.4
4	55.0	5.7	13.9	5.2	2.3	4.3	68.6	0.63	0.62	64.0

TABLE 5. PERFORMANCE OF PIGS ON FOUR LEVELS OF MANGANESE DURING GROWING-FINISHING PERIOD FROM 25 kg to 98.5 kg IN THE BOZEMAN TRIAL

Diet No.	1	2	3	4
Levels of added manganese, mg/kg	0	27.5	41.25	55.0
No. of pigs	10	10	10	10
Avg daily gain, kg[a]	0.83	0.83	0.80	0.81
Avg daily feed, kg	3.39	2.94	2.99	2.81
Avg feed gain ratio	3.62	3.72	3.74	3.50

[a]Least squares means adjusted for the regression of initial weight.

TABLE 6. CARCASS DATA FROM PIGS ON FOUR LEVELS OF MANGANESE DURING GROWING-FINISHING PERIOD FROM 25 kg TO 98.5 kg IN THE BOZEMAN TRIAL[a]

Diet No.	1	2	3	4
Levels of added manganese, mg/kg	0	27.5	41.25	55.0
No. of pigs	10	10	10	10
Yield, %	71.90	72.40	71.80	71.60
Backfat, cm[b]	2.90	2.72	2.78	2.67
Ham, %	14.70	15.10	15.00	15.00
Hame and loin, %	37.50	37.70	38.50	38.70
Lean cuts, %	52.90	53.50	54.40	54.80
Carcass length, cm[b]	78.36	77.44	77.07	77.55
Loin eye, cm^{2b}	31.00	32.55	33.57	34.58

[a]Least squares means.
[b]Adjusted to 99.8 kg.

TABLE 7. RESULTS OF ANALYSIS OF BLOOD SERUM, RIB AND METATARSAL FROM PIGS ON FOUR LEVELS OF MANGANESE IN THE BOZEMAN TRIAL[a]

Diet No.	1	2	3	4
Levels of added manganese, mg/kg	0	27.5	41.25	55.0
No. of pigs	10	10[b]	10	10[bc]
Blood serum, μg/L	11.5	8.2	10.4	9.4
Metatarsal				
Length, cm	9.8	9.7	9.6	9.8
Width, cm	2.7	2.7	2.6	2.7
Fat, %	14.8	14.3	14.9	16.0
Manganese, mg/kg	0.49	0.59	0.58	0.58
Rib, mg/kg	0.99	0.97	1.36	1.22

[a]Least squares means.
[b]One sample of rib and metatarsal from the 55.0 mg/kg group was lost.
[c]A serum sample was lost from each of 27.5 mg/kg and 55.0 mg/kg group.

TABLE 8. PROXIMATE ANALYSIS, CALCIUM, PHOSPHORUS AND MANGANESE CONTENT OF GROWER AND FINISHER DIETS FED TO PIGS IN MILES CITY TRIALS 1 AND 2

Diets	Protein %	Moisture %	Ash %	EE %	CF %	NFE %	Ca %	P %	Mn mg/kg
Trial 1									
Grower 1	17.8	7.2	5.3	2.0	5.0	62.7	0.68	0.62	48.0
Grower 2	17.6	7.2	5.3	2.0	5.3	62.9	0.73	0.62	60.0
Grower 3	17.1	7.2	5.1	2.1	4.6	63.9	0.70	0.59	66.0
Finisher 1	15.8	7.2	4.6	2.1	4.5	65.8	0.60	0.54	47.0
Finisher 2	15.6	7.3	4.9	2.1	4.5	65.6	0.69	0.57	59.0
Finisher 3	15.6	7.2	5.3	2.1	4.9	64.9	0.72	0.59	83.0
Trial 2									
Grower 4	16.5	7.1	4.3	1.9	4.6	65.3	0.51	0.53	31.0
Grower 5	16.0	7.2	4.0	2.0	4.9	65.9	0.39	0.48	34.0
Finisher 4	15.6	7.2	4.6	2.0	4.4	66.2	0.58	0.53	39.0
Finisher 5	15.7	7.1	4.2	2.0	4.5	66.5	0.48	0.51	45.0

TABLE 9. PERFORMANCE OF PIGS ON THREE LEVELS OF SUPPLEMENTAL MANGANESE DURING GROWING AND FINISHING PERIOD FROM 19.6 kg TO 98.7 kg IN MILES CITY TRIAL 1

Level of added manganese, mg/kg	27.5	41.25	55.0
No. of pigs	175	173	173
Avg daily gain, kg[a]	0.75	0.75	0.73
Avg daily feed, kg	2.59	2.67	2.62
Avg feed/gain ratio	3.53	3.65	3.62

[a]Least squares means adjusted for the regression of initial weight.

TABLE 10. PERFORMANCE OF BARROWS COMPARED TO GILTS ON THREE LEVELS OF SUPPLEMENTAL MANGANESE DURING GROWING-FINISHING PERIOD FROM 19.6 kg TO 98.7 kg IN MILES CITY TRIAL 1

Sex	Barrows			Gilts		
Level of added mn, mg/kg	27.5	41.25	55.0	27.5	41.25	55.0
No. of pigs	66	67	65	109	106	108
Avg daily gain, kg[a]	0.78	0.78	0.76	0.72	0.72	0.70

[a]Least squares means adjusted for the regression of intial weight.

TABLE 11. PERFORMANCE OF BARROWS ON ALL THREE LEVELS OF SUPPLEMENTAL MANGANESE COMPARED TO GILTS ON ALL THREE LEVELS OF SUPPLEMENTAL MANGANESE DURING GROWING-FINISHING PERIOD FROM 19.6 kg TO 98.7 kg IN MILES CITY TRIAL 1

Sex	Barrow	Gilt
No. of pigs	198	323
Avg daily gain, kg[a]	0.78[b]	0.71[c]

[a] Least squares means adjusted for the regression of inital weight.
[bc]Means were significantly different P<.01.

TABLE 12. PERFORMANCE OF PIGS ON TWO LEVELS OF MANGANESE WITH OR WITHOUT SUPPLEMENTAL BIOTIN DURING GROWING-FINISHING PERIOD FROM 18 kg TO 97 kg IN MILES CITY TRIAL 2

	Biotin		Manganese	
	0	50 µg	27.5 mg/kg	55.0 mg/kg
Avg daily gain, kg[a]	0.74	0.73	0.73	0.73
Avg daily feed, kg	2.57	2.59	2.60	2.57
Avg feed/gain ratio	3.54	3.58	3.58	3.53

[a]Least squares means adjusted for the regression of initial weight.

TABLE 13. PERFORMANCE OF BARROWS COMPARED TO GILTS ON TWO LEVELS OF MANGANESE DURING THE GROWING-FINISHING PERIOD FROM 18 kg TO 97 kg IN MILES CITY TRIAL 2

Sex	Barrows		Gilts	
Level of mn, mg/kg	27.5	55.0	27.5	55.0
No. of pigs	59	57	59	58
Avg daily gain, kg[a]	0.76	0.77	0.71	0.69

[a]Least squares means adjusted for the regression of initial weight.

TABLE 14. PERFORMANCE OF BARROWS COMPARED TO GILTS WITH OR WITHOUT SUPPLEMENTAL BIOTIN DURING THE GROWING-FINISHING PERIOD FROM 18 kg TO 97 kg IN MILES CITY TRIAL 2

	Barrows		Gilts	
Level of biotin, µg	0	50	0	50
No. of pigs	56	60	60	57
Avg daily gain, kg[a]	0.78[b]	0.75[c]	0.69[b]	0.70[b]

[a] Least squares means adjusted for the regression of intial weight.
[bc]Means within sex with different superscript letters are significantly different $P<.05$.

TABLE 15. PERFORMANCE OF ALL BARROWS COMPARED TO ALL GILTS DURING GROWING-FINISHING PERIOD FROM 18 kg TO 97 kg IN MILES CITY TRIAL 2

Sex	Barrows	Gilts
No. of pigs	116	117
Avg daily gain, kg[a]	0.77[b]	0.70[c]

[a] Least squares means adjusted for the regression of intial weight.
[bc]Means with different superscript letters are significantly different $P<.01$.

DISCUSSION

The results of all three trials agreed with Plumlee et al. (1956) who found that rate of gain and feed efficiency were satisfactory even on very low manganese levels in the diet. Since stiffness was not consistant in any of the treatments and no clear-cut variation in tissue levels were noted, it appears that 18 mg of manganese per kg of diet supplied by the barley-soybean meal diets was adequate for the growth requirements of pigs under the conditions of these trials. Since feedstuffs do vary considerably in mineral content from crop to crop, inclusion of a mineral premix supplying 27.5 mg of manganese per kg of diet is probably justified.

Supplemental biotin seemed unnecessary and in the case of barrows undesirable since 50 μg of supplemental biotin actually significantly depressed rate of gain. Therefore, barley-soybean diets appear to supply adequate levels of biotin for growing pigs.

Further work with both rats and pigs should be initiated to determine the true availability of manganese in barley.

SUMMARY

Three trials were conducted to study the effect of supplemental manganese on growing and finishing pigs. The pigs were fed 0, 27.5, 41.25 and 55.0 mg/kg of supplemental manganese in one trial; 27.5, 41.25 and 55.0 mg/kg of supplemental manganese in the second trial; and 27.5 or 55.0 mg/kg of supplemental manganese in combination with 0 to 50 µg of supplemental biotin. In the first trial, no differences were found in average daily gain, feed consumption, feed efficiency, carcass data or blood and bone tissue levels of manganese among groups on one of four levels of manganese. In the second trial, average daily gain, feed consumption and feed efficiency were nearly the same for pigs on all three levels of supplemental manganese. In the third trial, the level of manganese did not affect average daily gain, feed consumption or feed efficiency. However, there was a sex x biotin interaction for barrows on 50 µg of supplemental biotin compared to barrows on 0 µg of supplemental biotin. Barrows on both levels of supplemental manganese and biotin gained better than gilts on both levels of supplemental manganese and biotin.

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APPENDIX

APPENDIX TABLE 16. LEAST SQUARES ANALYSIS OF VARIANCE OF AVERAGE DAILY GAIN DATA FROM PIGS ON THE BOZEMAN TRIAL

Source	df	Mean squares
Total	40	
Total reduction	10	0.0748
Mμ-Y	1	0.3051
Sex	1	0.0022
Manganese level	3	0.0101
Breed	1	0.0125
Sex x manganese level	3	0.0584
Regression on initial weight	1	0.0140
Error	30	0.0201

APPENDIX TABLE 17. LEAST SQUARES ANALYSIS OF VARIANCE OF CARCASS DATA FROM PIGS ON THE BOZEMAN TRIAL

Source	df	Mean squares						
		Yield %	Backfat %	Ham %	Ham & Loin %	Loin cut %	Carcass length cm	Loin eye cm
Total	40							
Total reduction	9	1.2348	0.4655	1.1648	11.6420	12.3856	7.1035	35.2564
Mu-Y	1	0.1431	1.6790[a]	0.1427	0.2978	0.2925	11.2827	26.4174
Sex	1	0.3761	1.0391	9.3873[a]	62.7889[a]	71.9088[a]	20.4159[a]	173.4053[a]
Manganese level	3	1.1914	0.0890	0.2720	3.4142	7.3309	2.8281	22.3700[b]
Breed	1	0.8024	0.0001	0.0057	5.0147	1.4360	0.1548	0.0002
Sex x manganese level	3	1.8912	0.0410	0.0548	5.4815	4.8296	2.5900	3.2823
Error	31	1.4363	0.0949	0.2631	2.7720	5.1829	1.6987	5.5636

[a] P<.05.
[b] P<.10.