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Exploring How Maternal Phosphorus Status Affects Calf Growth and Performance

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Abstract

This study focused on how maternal phosphorus status of beef heifers affects the growth and performance of their calves. Heifers were offered free-choice mineral with either 0 or 4% supplemental phosphorus from 30 days after weaning until calving. A study by H. Hilfiker, a University of Arkansas honors student, investigated the effects of these treatments from 30 days after weaning until 60 days after the breeding season when heifers were confirmed to be bred or open. For this developing heifer project 64 crossbred Angus heifers were assigned randomly into 8 groups (8 heifers/group) before assigning each group to one of the two dietary treatments – 1) supplemented with phosphorus or 2) not supplemented. Heifers were synchronized and bred in November of 2019. In February of 2020, heifers confirmed to be pregnant continued onto this trial. Heifers remained on their previous treatments but were stratified by body weight and reassigned to pasture groups (to equalize group numbers) within treatment (36 heifers: 2 groups/treatment with 9 heifers/group).

At time of birth, colostrum samples were collected from a subset of 12 heifers/treatment (6 heifers/group) and evaluated for colostrum phosphorus and immunoglobulin concentrations. Serum samples were collected from calves at 48 hours postpartum to evaluate calf immunoglobulin concentrations. Data were analyzed using the MIXED (for continuous data) and GLIMMIX (for scoring data) procedures of SAS using group as the experimental unit. Cows grazed mixed grass pastures; monthly forage samples ranged from 0.28 to 0.36% phosphorus. There were no differences ($P > 0.10$) for heifer body weight during gestation, calf birth weight, calf viability scores at birth, or calf weight at an average age of 21 days. There were also no differences ($P > 0.10$) in colostrum components: fat, protein, lactose, and immunoglobulin G (IgG), or in the serum IgG or plasma mineral concentrations for both cows and calves 48 hours

after parturition. All calves were sampled at approximately 21 days of age, and there were no treatment differences ($P > 0.10$) in serum IgG concentrations. With no significant findings, research concludes that there are no benefits to supplementing gestating heifers with phosphorus when they graze pasture with a history of fertilization with livestock manure.

Introduction

The beef cattle industry is always looking for ways to increase gain performance and improve fertility of developing heifers and cows. The goal of this study is to evaluate phosphorus supplementation on primiparous cows and the effect on colostrum quality, calf growth, performance, and health. Colostrum is one of the main sources of minerals for newborn calves, especially calcium and phosphorus (Kume and Tanabe, 1993). In dairy calves, colostrum with high immunoglobulin concentrations led to weight gain in calves from birth to four days old, while low immunoglobulin concentrations led to weight loss (Nocek et al., 1984). If the same rationale can be applied to beef cattle, high immunoglobulin concentrations will increase weight gain during the first 4 days of life. Similar to immunoglobulin concentrations, colostrum with greater mineral content, phosphorus included, led to a decrease in calf mortality (Salih et al., 1987). Therefore, an increase in minerals, including phosphorus, could lead to greater immunoglobulin concentrations and in return an improved immune response and increased calf survival rate.

While phosphorus could lead to improved immune response and increased calf survival rate, phosphorus supplements may have a negative impact on the environment. When over-supplementation occurs, many nutrients are passed into the environment through manure and then into water sources. This process is unsustainable as it can ruin water sources for future farming and/or cities. Such is stated by researchers from University of Nebraska’s Department of

Animal Science, “removal of phosphorus supplements are important nutritional management options to help feedlots become more environmentally sustainable” (Klopfenstein and Erickson, 2002). As phosphorus is introduced to water systems, algae begins to grow at an increased rate. Many water ecosystems are not readily prepared to counteract the increased growth rates of algae and it leads to decreased oxygen levels in the water, lowering the water quality and the amount of aquatic life that can be supported in that body of water. Overgrowths of algae can also produce toxins that can be harmful to people if they consume the water, or any resources gathered from the water source (Nutrient Pollution, 2019).

Literature Review

Phosphorus is an essential macronutrient in beef cattle diets. For growing cattle, first calf heifers, cows, lactating and gestating cattle the dietary requirements of phosphorus differ. Gestating and lactating beef cattle require 0.20% of their diet to be phosphorus while growing cattle require 0.30% (Kniffen, and Comerford, 2021).

As an essential nutrient, phosphorus aids in the formation of bone and teeth. Phosphorus is needed in the diet to aid in energy transfer and the conversion of fat and carbohydrates to energy. In order for proteins required for growth, maintenance, and cellular repair to be formed, phosphorus must be present in the body. While phosphorus is vital in bodily functions, over supplementation should be avoided to maximize the efficiency, profit margins, and to reduce environmental pollution (Phosphorus in DIET, 2021).

Inadequate phosphorus concentrations in cattle diets lead to the following symptoms: “poor growth, reduced appetite, and reduced digestibility of feedstuffs” (Simms, 2013). The inverse could also be true, adequate levels must lead to adequate growth and with increasing phosphorus concentrations, growth may also increase if levels are not raised to a toxic level.

Increasing phosphorus concentrations have also been linked to increased pregnancy rate and a higher live birth rates in puberty aged heifers (Call et al., 1978). Increased phosphorus concentrations in feed have been linked to increased birth rates, increased gain performance, and decreased calf mortality.

One study evaluated phosphorus supplemented calves through feedstuffs with access to milk starting at 90 days of age. While phosphorus supplementation did not affect suckling time or frequency, the average daily gain, final body weight, and body condition scores indicated that supplemented calves gained more than non-supplemented calves (Valente et al., 2012). The study indicated that both cow and calf have a positive response to supplementation, which suggests that phosphorus supplementation to cows could lead to a transfer of the mineral to their calves and show a significant increase in growth, performance, and health.

If supplemental phosphorus is proven to be necessary or not, then an educated decision can be made by farmers on supplementation provided to their cattle. By providing this information, one can choose to make the most economically, efficient, and environmentally friendly decision for the supplement provided based on their soil nutrient levels.

Materials and Methods

The following procedures were reviewed and approved by the University of Arkansas Animal Care and Use Committee (IACUC) before the project began. For this experiment, heifers (n = 64) weaned in May 2019 from the University of Arkansas System Division of Agriculture Experiment Station Beef Cow Calf Unit near Fayetteville were used. Approximately 30 days after weaning, heifers were weighed, stratified by body weight, and divided randomly into 8 groups (8 heifers/group). Each group was then assigned randomly to one of two dietary treatments (Table 1) – 1) supplemented with phosphorus (4% in a free-choice-mineral mix) and

2) no supplemental phosphorus in an otherwise identical free-choice-mineral mix formulated to meet all other mineral and vitamin requirements. Heifers were allowed to graze 8 mixed grass pastures (2.4 ha/each) and received supplemental soybean hulls (0.5% of body weight each day adjusted after each weigh day). Soil phosphorus concentrations in pastures ranged from 130 to 259 ppm. The forage, soybean hulls, and mineral supplements were sampled every 28 days throughout the course of the study. Heifers continued on these dietary treatments for the remainder of the trial and body weights (BW) were recorded every 28 days.

In November of 2019, heifers were synchronized and bred by artificial insemination (AI) followed by natural service. Data were collected by H. Hilfiker for her UA Honors research project at that time and have been previously reported (Hilfiker, 2020). In February 2020, a portion of the heifers with a confirmed pregnancy continued onto this trial. Bred heifers were stratified by body weight and re-assigned randomly within treatment to 1 of 2 groups (9 heifers/group). Each treatment had a similar number of heifers, 18, confirmed pregnant by either artificial insemination or natural service and had similar average body weight. Pregnant heifers continued receiving the same dietary treatment to which they were originally assigned. Available forage, hay (when offered), and soy hulls were sampled monthly. Heifer body weights, hair coat scores, and body condition scores were obtained at approximately 56-day intervals. Hair coat scores were evaluated using the American Angus Association Hair Shedding Scoring Guide on a 1 to 5 scale with a score of 1 describing a short, slick coat and a score of 5 describing a full winter coat (American Angus Association Hair Shedding Scoring Guide). Body condition scores were assigned using a scoring scale of 1 to 9 where a score of 1 describes a thin cow with spine, ribs, and hip bones visible and no fat on the brisket, flanks, or tail head. A score of 9 describes an extremely heavy cow with no spine, ribs, or hip bones visible and extreme fat on the brisket, flanks, and tail head. An ideal score for gestating and lactating heifers and cows is 5 to 6 where there are no visible spine or ribs with a defined outline of hip bones visible and some fat in the brisket and flanks (Eversole et al., 2009).

The heifers began calving in August of 2020. Two weeks prior to the anticipated calving date, heifers were moved nearer the working facility to smaller (0.45 ha) grass lots. A subset of heifers (12 heifers/treatment, 6 heifers/group) were selected for additional sample collection. At the time of birth, a pooled colostrum sample from all four quarters was collected from each of these heifers. The colostrum samples were evaluated for the following: 1) colostrum phosphorus concentrations and other minerals, 2) colostrum immunoglobulin G (IgG) concentrations, and 3) colostrum proximate analysis measuring percentages of fat, protein, lactose, ash, and solids not fat, and a somatic cell count. Subsamples of colostrum were frozen at -20° C for later mineral and immunoglobulin analyses, and a subsample for proximate analysis was placed in a sample vial provided by the commercial lab that contained a pellet of preservative, mixed thoroughly, and stored at room temperature until shipped by overnight mail to the Mid-South Dairy Records Laboratory (Springfield, MO) once each week. At 48 hours after birth, blood samples were collected from these cows and calves by jugular venipuncture. Blood for serum to be used to evaluate IgG concentrations was collected in vacuum tubes with a clot activating compound. Blood for plasma mineral determinations was collected in vacuum tubes manufactured for trace mineral determinations. Anticoagulated whole blood samples for complete blood count analysis were collected in vacuum tubes containing EDTA. Blood was refrigerated until centrifuged at 2,100 × g for 20 min, then serum and plasma were stored frozen at -20° C. Whole blood was refrigerated for up to 48 hours before being evaluated for white and red blood cell values using an automated analyzer (HemaVet HV950; Drew Scientific, Miami Lakes, FL).

All heifers were evaluated during the calving process. Calf birth weights and gender were recorded as well as calving ease scores, and calf vigor, thriftiness, and agility scores for every calf. Calving ease scores are as described by the Beef Improvement Federation (2018). Calf vigor scores were: 1 = alert and active, 2 = alert, 3 = appears healthy, but somewhat listless, 4 = listless, and 5 = listless and unresponsive. Calf thriftiness scores were: 1 = nursed immediately, calf was healthy at birth, 2 = nursed on own, but took time, 3 = required some assistance to suckle, 4 = died shortly after birth, and 5 = dead on arrival. Calf agility scores were: 1 = moves well and correct posture, 2 = moves showing slight stiffness in legs, 3 = significant stiffness in gait, 4 = significant stiffness in gait and slight arch in the topline, and 5 = significant stiffness in gait and arch in topline.

All calves were weighed and bled at approximately 21 days of age. There were three sampling dates – September 14, October 2, and October 21; and actual calf age ranged from 15 to 36 days of age. Blood was handled similarly, and serum was used to determine IgG concentrations.

Laboratory Analyses

Forage and supplement samples were composited and dried in a forced air oven then ground using a Wiley Mill (Thomas Scientific, Swedesboro, NJ) through a 1 mm screen. Mineral mix samples were dried but not ground. Ground samples were analyzed for crude protein (Rapid Combustion Method, Elementar Americas, Inc., Mt. Laurel, NJ), neutral detergent fiber, and acid-detergent fiber (ANKOM Techonology Corp., Fairport, NJ; Vogel et al., 1999). All samples were prepared for mineral analysis by wet ashing and analyzed by inductively coupled plasma spectroscopy (Model 3560, Appied Research Laboratory, Sunland, CA) at the University of

Arkansas System Altheimer Laboratory (Fayetteville, AR). Nutrient analyses are presented in Tables 2 and 3.

Colostrum and serum immunoglobulin concentrations were determined by commercial anti-bovine IgG radial immunodiffusion kits (Immunology Consultants Laboratory, Inc., Portland, OR). The intra-assay CV was 7.3% and the inter-assay CV was 2.5%.

Statistical Analysis

Continuous data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, N.C.) with pen set as the experimental unit for all variables. Compound symmetry was specified as the covariance structure. Data for scores (body condition, hair coat, calving ease, vigor, thriftiness, and behavior) were analyzed using the GLIMMIX procedure with pen set as the experimental unit. All calves had an agility score of 1, thus no statistical procedures were attempted for that data. For heifer data, treatment was the only fixed effect and replicate was the random effect. For calf growth performance data, treatment was the only fixed effect and replicate and sex were specified as random effects. Kenward Rogers was specified as the degrees of freedom selection method in the mixed procedure. Mineral intake data were analyzed as a repeated measure and the model included treatment, period, and the treatment by period interaction. All data were checked for normality using the UNIVARIATE procedure of SAS. Non-normal data were log transformed before further statistical analysis to improve normality. For the purpose of this study, $P < 0.1$ was considered significant.

Results and Discussion

In this study, both groups of heifers grazed similar pastures and were offered identical rations of soyhull pellets. Each group's treatment of 0 or 4% phosphorus was delivered via free choice mineral. The mineral offered was designed for a 113 g/day intake. There was no effect (P = 0.46) of treatment on average mineral intake with control averaging 99 g/day and supplemental phosphorus averaging 90 g/day. However, there was a treatment × period interaction (P = 0.01; Figure 1) for mineral intake with the greatest intake of mineral (121 g/day) by the control heifers in the final period of the trial.

Forage Analysis

Forage samples were analyzed to determine neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP) and ash (Table 2). Forage composition shows consistent NDF and ADF values until May of 2020 where NDF spiked at 73% and ADF peaked at 34.71%. Values may have been elevated that month due to decreased precipitation in the area. Additional hay and soyhull pellets provided throughout the study contributed significantly to NDF (hay) and ADF (soyhull pellets) offered to the heifers. Ash values varied throughout the study with the greatest value in April and the lowest value reported as an average of soyhull pellets offered.

Phosphorus Requirements

First calf heifers that are approximately 464 kg require 0.13 to 0.18% of their diet to contain phosphorus (dry matter intake) throughout gestation and lactation (Nutrient Requirement Tables, 2018). Table 3 illustrates that the phosphorus concentrations of the mineral provided to both treatments were well over the minimum requirements for gestating and lactating first calf heifers. The control group was offered 0.28% while the phosphorus group was offered 3.44% phosphorus in the mixed mineral ration. Of this offered amount, each heifer consumed approximately 100 g per day. In addition to the mineral mix, the forages, hay and soyhull pellets contributed to phosphorus concentrations ensuring that heifers were well over their minimum requirements. The majority of the heifers' diet was supplied as forage. Table 3 highlights the phosphorus percentages in the randomly collected forage samples, each months' forages had phosphorus concentrations greater than the minimum requirements for each heifer.

Heifer Body Condition Score, and Hair Coat Score

Heifers were evaluated for body condition scores (BCS) and hair coat scores (HCS) bimonthly throughout this study. Hair coats of heifers have been shown to have an effect of the 205-day weight of their calves. The slicker the coat (score of 1) the higher the 205-day weight of the calves (Gazda, 2011). The hair coat scores of the control and the phosphorus groups were not different. High body weight and high body condition scores are crucial in the reproductive cycle of heifers. Heifers with a body score of 6 have been found to have the optimal chances to become and maintain pregnancy (Dickinson et al., 2019). The control and phosphorus groups maintained the body condition score of 6, meaning that all dietary requirements were met, and the heifers were in the appropriate condition to deliver a live calf.

Calf Performance

Each calf was evaluated at birth and scored for vigor, thriftiness, agility, calving ease, and behavior (Table 5). Cows offered the phosphorus supplement experienced no difference ($P > 0.10$) in calving ease and calves did not perform any differently ($P > 0.10$) in each treatment. Calves were weighed at birth and at approximately 21 days postpartum to evaluate calf performance and average daily gain (ADG). Actual calf ages range from 15 to 36 days of age. In a ten-year study at the University of Arkansas Livestock and Forestry Branch Station and Southwest Research and Extension Center, the expected average daily gain for fall calves is 2.5

lb/day or 1.4 kg/day (Chapter 9: Keys to Success in Stocker Programs, 2016). Calves whose dams received the non-supplemented mineral mix performed just as well in all aspects as the calves whose dams received the phosphorus supplemented mineral mix.

Colostrum Composition

Colostrum samples collected from each heifer within 12 hours postpartum were analyzed for fat and protein content as well as mineral content. Table 6 reports the fat, protein, lactose, solids-not-fat (SNF), somatic cell count (SCC) and IgG averages. Colostrum composition changes quickly in the hours following birth therefore a range of values will be considered normal for the purpose of this study. Normal protein percentages of colostrum can range from 16.8% immediately following birth to 6.3% at 12 hours after calving. Percentages of fat composition are less volatile and change slower, for fat normal ranges are from 6.7 to 4.4%. Lactose increases in concentration as more time passes. Normal lactose concentrations will be considered 2.9 to 3.9% (Puppel et al., 2019). Data for fat, protein, and lactose percentages were within the normal ranges as defined above. There were no significant differences between the control and the phosphorus group for percentages of fat (P = 0.58), protein (P = 0.23), and lactose (P = 0.20). Normal IgG concentrations for colostrum should be at or around 48 mg/ml (Sellers, 2001). Immunoglobulin G concentrations were 41 mg/ml for heifers on the control treatment and 51 mg/ml for heifers on the phosphorus treatment. The phosphorus treatment did have the more normal of the two treatments, but there was no significant difference between the two treatments (P = 0.38).

Colostrum samples were also evaluated for phosphorus content using inductively coupled plasma – atomic emission spectroscopy following ashing. For the purpose of this study, normal colostrum phosphorus percentages at the time of calving are 0.235% (Puppel et al., 2019). The recorded phosphorus concentrations for both the control and the phosphorus group are below the presumed normal concentration as noted in Table 7. While both percentages were lower than normal, there was no significant difference between the control and the phosphorus treatments. However, there was a tendency (P = 0.11) for the phosphorus supplemented heifers to have greater phosphorus in their colostrum at the time of calving. While not a focus of this study, colostrum calcium concentrations varied between the two treatments (P = 0.02). Normal percentages of calcium in colostrum are 0.256 (Puppel et al., 2019). The control and the phosphorus treatments were both below average, with percentages of 0.18 and 0.20 as shown in Table 7.

Complete Blood Counts

As noted by Table 8, the complete blood counts for the heifers were within normal limits and had no differences between heifers on the control and the phosphorus treatments. Table 9 discussed the results of the complete blood counts for the calves. All data were within normal limits, except for percentage of red cell distribution width (RDW). The calves from the control treatment had RDW of 23.86% while calves from the phosphorus treatment had 24.74% (P = 0.04). Varying data within the red cell distribution width can be caused by underlying anemia or iron deficiency, which can be explained due to collecting blood samples from young calves who have not yet received full passive immunity from colostrum (RDW (red CELL distribution WIDTH): Medlineplus medical test, 2020). Complete blood counts revealed that phosphorus supplementation had no effect on dam or calf.

Serum IgG

Normal IgG values in calves are 12.3 to 29.1 mg/mL at 24 hours after calving (Godden et al., 2009). At or before 12 hours postpartum the calves from the control treatment and the phosphorus treatment had values within the parameters set above. As illustrated in Table 10, IgG concentrations of the calves from the control treatment and the phosphorus treatment at birth were very similar (P = 0.88) and the IgG concentrations at day 21 had no significant difference (P = 0.66).

Plasma minerals

Blood samples obtained at the 48 hours after calving were evaluated for plasma mineral concentrations. Normal concentrations have been interpreted from a study involving young dairy cattle. Normal cow plasma mineral concentrations of phosphorus are 5.6 mg/dL (McAdam and O'Dell, 1982). As stated in Table 11, the heifers on the control treatment had 6.88 mg/dL of phosphorus and heifers on the phosphorus treatment had 7.06 mg/dL. Heifers on both treatments had concentrations greater than average for phosphorus, likely because of the increased phosphorus concentrations in the pastures they were allowed to graze. While both concentrations were elevated, the heifers on the two treatments had no significant differences in phosphorus concentrations (P = 0.62). It is important to note that plasma magnesium concentrations for the heifers had significant differences (P = 0.02). The cows on control treatment had magnesium concentrations at 2.58 mg/dL and the heifers on the phosphorus treatment had concentrations of 2.42 mg/dL. Normal magnesium concentrations obtained from the same study used above, are 2.01 mg/dL (McAdam and O'Dell, 1982). Concentrations for heifers on both treatments were elevated. Calf plasma mineral concentrations had no significant differences. While no normal concentrations could be obtained for calf plasma mineral concentrations, one can assume that since the heifers on both treatments had elevated phosphorus concentrations, their calves also have elevated phosphorus concentrations.

Conclusion

The purpose of this study was to determine if the maternal phosphorus status of heifers affects the growth and performance of their offspring. Data collected over the course of this study indicates that offering phosphorus as a supplemental mineral to heifers throughout gestation does not affect the growth or performance of their calves. This study strongly indicates that when grazing soil that has adequate amounts of phosphorus, supplementation is not needed. Forages cattle were grazed on contained 0.28% phosphorus at minimum and 0.36% phosphorus at maximum, providing more than adequate levels of phosphorus for the heifers' diets. While offering mineral that includes phosphorus has no negative effects on dam or calves, it is also not economically advantageous to farmers and may cause harm to the environment when used unnecessarily.

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Table 1. Composition of free choice mineral mixes used to deliver dietary treatments.

Ingredient	Control	Supplemental P
Calcium, %	20	20
Phosphorus, %	0	4
Salt, %	24 to 26	24 to 26
Magnesium, %	0.2	0.2
Potassium, %	0.1	0.1
Copper, mg/kg	2,500	2,500
Selenium, mg.kg	26	26
Zinc, mg/kg	10,000	10,000
Vitamin A, IU/kg	440,000	440,000
Vitamin D3, IU/kg	22,000	22,000
Vitamin E, IU/kg	22	22

Table 2. Composition (dry matter basis) of forage, hay, and soy hulls

Date	NDF, %	ADF, %	CP, %	Ash, %
March	59.31	29.19	16.98	7.85
April	58.78	25.99	20.27	8.81
June	63.62	33.38	12.89	7.46
July	68.86	33.41	12.92	7.00
August	70.70	30.07	15.06	7.27
September	67.18	29.04	15.11	7.53
October	62.90	29.62	11.74	7.42
Hay	72.82	35.84	9.91	4.99
Soyhull Pellets	65.31	45.76	11.24	4.98

Table 3. Mineral composition (DM basis) of minerals mixes, forage, hay, and soyhull pellets

Feed	P, %	K, %	Ca, %	Mg, %	S, %	Na, %	Fe, mg/kg	Mn, mg/kg	Zn, mg/kg	Cu, mg/kg
Mineral with no added P	0.28	0.48	16.70	0.37	1.38	7.22	3426.78	1061.35	13164.60	5307.55
Mineral with supplemental P	3.44	0.30	16.36	0.24	1.07	7.11	6212.66	1090.60	8196.80	4760.36
1/27 Hay	0.36	1.58	0.49	0.38	0.14	0.03	71.94	161.75	56.74	6.43
3/20 Grass	0.34	2.39	0.42	0.19	0.22	0.01	115.62	113.98	44.04	7.37
4/20 Grass	0.36	2.32	0.43	0.18	0.22	0.004	319.07	108.08	51.26	8.18
6/20 Grass	0.33	2.14	0.38	0.18	0.17	0.017	166.01	109.54	40.55	7.49
7/20 Grass	0.30	1.83	0.46	0.20	0.18	0.010	113.06	92.07	40.76	6.00
8/20 Grass	0.29	2.00	0.38	0.18	0.24	0.008	126.92	139.49	62.00	6.72
9/20 Grass	0.32	2.12	0.44	0.21	0.24	0.010	99.05	89.80	57.67	6.48
10/20 Grass	0.28	2.11	0.51	0.23	0.20	0.013	107.14	73.86	46.12	5.36
Soyhull Pellets	0.10	1.22	0.64	0.24	0.10	16.24	424.48	13.64	36.62	5.09

Table 4. Effect of phosphorus concentration in the mineral offered on heifer body weights, hair coat scores, and body condition scores.

	Control	Phosphorus	SE	*P* - value
Body weights				
February, kg	427	422	7.8	0.69
April, kg	465	460	6.9	0.66
June, kg	498	494	10.7	0.79
August, kg	502	496	5.1	0.49
Hair coat scores				
April	3.72	3.56	0.44	0.79
June	2.78	3.16	0.40	0.50
August	3.12	3.16	0.42	0.94
Body condition scores				
June	6.16	6.33	0.58	0.84
August	6.00	5.94	0.58	0.94

Table 5. Effect of phosphorus concentration in the mineral offered to heifers on calf growth performance and subjective scores at calving.

	Control	Phosphorus	SE	*P* - value
Birth weight, kg	27.34	27.81	2.40	0.90
Body weight, day 21, kg	49.12	52.04	2.23	0.40
Average daily gain, day 0 to 21, kg	1.06	1.12	0.05	0.38
Vigor	1	1.15	0.26	0.69
Thriftiness scores	1	1.15	0.26	0.69
Agility[A]	1	1	--	--
Calving Ease Scores	1.06	1.15	0.71	0.80
Behavior scores	3.94	4.08	0.51	0.86

[A]All calves were scored a 1 so no statistical procedures were used.

Table 6. Effect of phosphorus concentration in the mineral offered to heifers on colostrum content.

	Control	Phosphorus	SE	*P* - value
Fat, %	5.05	5.93	--[A]	0.58
Protein, %	11.49	12.70	0.51	0.23
Lactose, %	3.06	2.58	0.18	0.20
Solids not fat, %	15.10	15.64	0.23	0.24
Somatic cell count, n x 1000/ml	7.24	7.20	--[A]	0.80
IgG, mg/ml	41	51	6.26	0.38

[A]Data were log transformed to improve normality, SE = 0.18 for the log-transformed percentage fat, and SE = 0.10 for the log-transformed somatic cell count

Table 7. Effect of phosphorus concentration in the mineral offered on mineral concentrations in colostrum (n=12/treatment)

	Control	Phosphorus	SE	*P* - value
Phosphorus, %	0.15	0.17	0.00	0.11
Potassium, %	0.14	0.12	0.01	0.36
Calcium, %	0.18	0.20	0.00	0.02
Magnesium, %	0.02	0.04	0.00	0.34
Sulfur, %	0.12	0.16	0.02	0.30
Sodium, mg/kg	891.92	1057.86	43.21	0.11
Zinc, mg/kg	22.90	35.28	3.79	0.14
Copper, mg/kg	0.10	0.13	0.01	0.23

Table 8. Effects of phosphorus supplementation on cow complete blood counts

	Control	Phosphorus	SE	*P*- value
White blood cells, K/µL	7.84	9.06	0.75	0.36
Neutrophil, %	42.28	46.04	2.68	0.42
Lymphocyte, %	48.58	43.96	2.24	0.28
Monocyte, %	4.06	4.78	0.34	0.28
Eosinophil, %	4.88	4.52	0.38	0.58
Basophil, %	0.44	0.68	0.18	0.44
Red blood cells, M/µL	7.75	7.90	0.34	0.78
Hemoglobin, g/dL	9.67	9.30	0.86	0.78
Hematocrit, %	34.50	35.16	0.90	0.66
Mean corpuscular volume, fL	44.56	44.57	0.80	1.00
Mean corpuscular hemoglobin, pg	12.47	11.76	0.86	0.62
Mean corpuscular hemoglobin concentration, g/dL	28.00	26.53	1.91	0.64
Red cell distribution width, %	20.60	20.81	0.24	0.60
Platelet count, K/µL	242.29	386.58	44.70	0.15
Mean platelet volume, fL	7.92	8.92	0.50	0.30

Table 9. Effects of phosphorus supplementation on calf complete blood counts

	Control	**Phosphorus**	**SE**	***P* - value**
White blood cells, K/µL	5.37	5.92	0.16	0.16
Neutrophil, %	53.02	55.93	3.04	0.56
Lymphocyte, %	38.66	36.11	3.38	0.64
Monocyte, %	4.86	5.02	0.32	0.80
Eosinophil, %	3.01	2.92	0.66	0.93
Basophil, %	0.26	0.30	0.08	0.74
Red blood cells, M/µL	8.64	8.50	0.48	0.85
Hemoglobin, g/dL	8.69	8.07	0.92	0.68
Hematocrit, %	29.76	29.54	2.58	0.96
Mean corpuscular volume, fL	34.30	34.51	0.99	0.89
Mean corpuscular hemoglobin, pg	9.96	9.36	0.52	0.50
Mean corpuscular hemoglobin concentration, g/dL	29.10	27.10	0.80	0.21
Red cell distribution width, %	23.86	24.74	0.10	0.04
Platelet count, K/µL	293.88	307.83	22.83	0.72
Mean platelet volume, fL	6.45	6.86	0.34	0.48

Table 10. Effect of phosphorus concentration of heifers' colostrum on calf serum

	Control	Phosphorus	SE	*P*- value
Birth IgG, % Log formation	19.0	19.6	--	0.88
Day 21, % Log Formation	11.0	12.0	--	0.66

[A]Data were log transformed to improve normality, SE = 0.126 for the log-transformed birth IgG in ng/ml, and SE = 0.10 for the log-transformed IgG at day 21 in ng/ml.

Table 11. Effect of phosphorus in the mineral offered on mineral concentrations of cow plasma minerals

	Control	Phosphorus	SE	*P*- value
Phosphorus, mg/dL	6.88	7.06	0.14	0.47
Potassium, mg/dL	18.94	21.42	0.92	0.20
Calcium, mg/dL	9.68	9.57	0.16	0.68
Magnesium, mg/dL	2.58	2.42	0.02	0.02
Sodium, mg/ dL	339.67	337.51	0.92	0.24
Iron, mg/dL	0.09	0.10	0.00	0.40
Zinc, mg/dL	0.56	0.55	0.00	0.62
Copper, mg/dL	0.13	0.14	0.00	0.35

Table 12. Effect of phosphorus in the mineral offered on mineral concentrations of calf plasma minerals

	Control	Phosphorus	SE	*P*- value
Phosphorus, mg/dL	9.16	9.50	0.44	0.62
Potassium, mg/dL	25.35	29.54	1.12	0.12
Calcium, mg/dL	11.70	11.45	0.31	0.62
Magnesium, mg/dL	2.08	2.13	0.07	0.72
Sodium, mg/ dL	5.11	5.15	0.73	0.97
Iron, mg/dL	320.57	321.02	0.98	0.78
Zinc, mg/dL	0.06	0.08	0.02	0.51
Copper, mg/dL	0.44	0.46	0.00	0.10
Phosphorus, mg/dL	0.05	0.06	0.00	0.67

Figure 1. Effect of phosphorus in the mineral offered on daily mineral intake