EFFECT OF DIFFERENT RATIOS OF CALCIUM TO PHOSPHORUS ON LACTATING COWS

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TO PHOSPHORUS ON LACTATING COWS

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INTRODUCTION

Two major changes in dairy cattle feeding have drawn attention to the possibilities of encountering a shortage or an imbalance of certain minerals. The first change resulted from efforts to improve the quality of forage crops and their yield per acre. The tendency has been to use higher rates of fertilization and liming. Ward (57) has cited work in which an increase in fertilization and liming may alter the mineral composition of the forage. An increase in the calcium content of forage usually follows lime applications to the soil. Other changes in composition resulting from liming are decreased content of phosphorus, iron and manganese, and increased level of protein. Hay from fertilized soil contained significantly more ash, calcium, phosphorus, potassium, and copper, and significantly less manganese, than that from the unfertilized soil. Grain mixtures from fertilized areas contain significantly more phosphorus.

When legumes and grains raised under conditions of high fertilization and liming are included in a so-called high roughage feeding system it is possible to get calcium to phosphorus ratios of 4:1 or higher. Due to artificial insemination and continuous selection for cows having a potential for high milk production dairymen have found it profitable to feed high levels of grain. This change tends to offset the problem present in the high roughage feeding system. When cows which have a high production potential are fed a high grain ration they are challenged to produce at a maximum level and their total nutrient requirements are quite different from the requirements of cows producing at a lower level.

All animals have a dietary need for calcium and phosphorus and the demand for these elements increases during growth, reproduction, and lactation. Although dairy cattle have specific requirements for calcium and phosphorus, the ratio in which these elements are fed is as important as the level at which they are fed.

There is some evidence that low or high levels of either calcium or phosphorus or an imbalance of calcium to phosphorus is associated with an increased incidence of parturient paresis, silent estrous periods, and decreased milk and fat production. The specific objectives of this experiment were to determine what effect, if any, different ratios of calcium to phosphorus would have upon milk composition and yield, the occurrence of parturient paresis, and the reproductive performance of dairy cows.

LITERATURE REVIEW

Effect on Nutrient Utilization

Several workers (22, 54) have shown that the utilization of dietary calcium is a function of physiological need. Kleiber et al. (38) found that endogenous fecal phosphorus was positively correlated with the level of feed intake; however, "true" digestibility of phosphorus was higher with a low level of feed intake. Ellenberger et al. (13) and Forbes and Beagle (17) stated that the metabolism of calcium and phosphorus followed an annual cycle of lactation and gestation. Negative balances occurred during early lactation, but during late lactation and the dry period adequate body reserves were regained. More recently, Richter and Oslage (46) found that calcium and phosphorus retention tended to increase with advancing lactation and stages of gestation. Similarly, Keller (36) reported that during the first few days postpartum calcium digestibility was low, and that with advancing lactation there was an increase in the calcium balance.

As cows get older, their ability to absorb, mobilize, and retain calcium decreases (7, 21, 22). In an experiment with Hereford calves, Hansard et al. (22) found that absorption of calcium was high in young animals, decreased rapidly until puberty, decreased more slowly until maturity, and was quite low in aged animals. Increasing age and body weight resulted in increasing daily endogenous fecal calcium, which also contributed to a lower retention of calcium as the animals became older.

The fundamental result of feeding massive oral doses of vitamin D appears to be an increase in the rate and quantity of calcium and phosphorus absorbed from the digestive tract (10). This effect was accompanied by a decreased excretion of these minerals into the intestinal tract and thus an increase in net retention of calcium and phosphorus (9, 10, 23, 55). Hibbs and Conrad (23) found that when the phosphorus balance is positive there is an increase in calcium absorption in the cows fed vitamin D; however, where the phosphorus balance was negative it was found that vitamin D did not increase calcium absorption.

Reid (45) pointed out that cows adjusted to low calcium diets performed satisfactorily on an intake of calcium which was below the theoretical requirement, suggesting relatively inefficient utilization of calcium by unadjusted cows fed usual rations high in calcium. Contrasting results were noted by Luick et al. (41) in that cows receiving rations low in calcium in relation to phosphorus utilized the calcium less efficiently than cows fed rations higher in calcium. These workers also observed that lactating cows utilized dietary calcium more efficiently than the nonlactating cows, and pregnant cows utilized dietary calcium more effectively than nonpregnant cows. The cows fed a Ca:P ratio of 1:1 were better able to maintain calcium balances than those fed a 1:7 ration.

Smith et al. (47) stated that as the calcium and phosphorus ratio is significantly changed from the normally recommended range of 1:1 there will be a reduction in the efficiency of the utilization of both calcium and phosphorus. However, Leuker and Lofgreen (40) found that feeding rations containing Ca:P ratios of 0.8:1, 2.8:1 and 6.0:1 to growing lambs had no effect on the amount of calcium or phosphorus absorbed. The amount of either calcium or phosphorus absorbed was directly related to the amount fed.

Keller (36) pointed out that estrus had adverse effects on apparent digestibility and retention of calcium.

Colovos et al. (8) found that the addition of 2% limestone to the grain mixture significantly depressed the digestibility of both energy and protein in a ration composed of grass hay and a 16% protein grain mixture. Smith et al. (47) observed a depressed digestibility of crude fiber when calves received a ration with a Ca:P ratio of 1:1. As the Ca:P ratio widened a depression in the digestibility of organic matter and nitrogen-free extract occurred. However, the digestibility of ether extract increased considerably as the ratio of Ca:P increased.

Blood Serum Levels of Calcium and Phosphorus

Payne and Leech (43) analyzed blood plasma from 279 cows for calcium and inorganic phosphorus. The average concentrations of calcium and inorganic phosphorus were 10.65 and 5.23 mg/100 ml, respectively. The inorganic phosphorus level was consistently lower in lactating cows than in dry cows. The concentrations of calcium and phosphorus were not affected by the milk yield in the previous lactation or by pregnancy. However, a slight decline in the plasma calcium level was associated with increasing age.

Hibbs et al. (25, 28, 29) and Conrad et al. (10) found that the feeding of vitamin D orally brought about an increase in the level of blood serum calcium and phosphorus.

Halse (20) reported that when cows were starved for 2 days there was a rapid decrease in blood calcium and phosphorus.

The work of Stott and Smith (50) showed that a partial or complete parathyroidectomy of cows caused a decrease in serum calcium and plasma inorganic phosphorus levels. However, Pappenhagen (42) observed that when parathyroid hormone was administered within two hours postpartum the blood levels of calcium, magnesium, and phosphorus were not altered in first calf heifers and mature animals which had never had milk fever, or in those animals which previously had milk fever, but did not develop it at this calving.

Boda and Cole (6) reported that there was a slight fall in serum calcium and a slight rise in the inorganic phosphorus level at parturition when cows had received a low calcium-high phosphorus diet (ratio 1.3:3) for 2-3 months prepartum. There was approximately a 1 mg/100 ml reduction in calcium values and no appreciable differences in phosphorus serum levels at parturition when cows were on a high calcium-high phosphorus ration (ratio 1:1) fed 5-45 days prepartum. The blood serum calcium levels were approximately 1 mg/100 ml lower on the first day postpartum, when the cows received a high calcium ration 20-40 days prepartum, as compared with a low calcium ration 9-23 days prepartum. In more recent work, Boda and Cole (7) found that on the day of parturition the fall in blood serum calcium was not significantly different in the animals receiving the high calcium, the normal calcium, or the low calcium rations, excluding cows with outward symptoms of milk fever. Ward (56) and Blosser and Smith (5) also observed lower serum calcium levels at the time of parturition. Jackson et al. (35) reported that at the time of parturition mature animals showed a greater decrease in calcium and inorganic phosphorus and a greater increase in magnesium than did younger animals.

Boda and Cole (6) and Blosser and Smith (5) observed that in milk fever cows the calcium level was markedly lower than in normal cows. Milk fever symptoms were accompanied by calcium values which were approximately 1 mg/100 ml lower than for normal cows on the day of parturition (6). In addition to the drop in serum calcium, a decrease has been noted in serum inorganic phosphorus (15, 24, 25, 61). Kendall and Harshbarger (37) found that the blood serum level was 7.76 mg calcium/100 ml and 2.77 mg phosphorus/100 ml for cows having milk fever, whereas the serum levels for cows during lactation were 9.9 mg calcium/100 ml and 4.35 mg phosphorus/100 ml. Boda and Cole (6) cited other work in which the severity of the milk fever symptoms was roughly proportioned to the fall in serum calcium.

In an experiment by Smith et al. (47) Holstein cows were fed Ca:P ratios of 1:1, 4:1, 8:1, 8:2, and 8:8. The ratio designed to give the 1:1 ratio was constructed so that the phosphorus level would be equal to the recommendations of the National Research Council (NRC). The cows which received the diets containing the Ca:P ratios of 8:2 and 8:8 showed significant increases in serum phosphorus. The authors believed that this increase was due to a function of the level of phosphorus being fed rather than to the specific ratio.

Dowe et al. (11) fed steer calves rations with Ca:P ratios of 1.3:1, 4.3:1, 9.1:1, and 13.7:1 and found that excessive calcium intake had no effect on the blood plasma level. The level of phosphorus fed was approximately 12 g per calf per day. In a more recent report, Swenson et al. (52) found similar results, with a Ca:P ratio as wide as 10:1.

Smith et al. (47) pointed out that the ratio of Ca:P influences the level of carotene found in the blood serum, with a higher level of carotene at the wide Ca:P ratio. The carotene content of the serum was more closely related to the ratio of calcium to phosphorus consumed than to the level of phosphorus in the diet.

Milk Production

Lenkett et al. (39) found that cows' milk averaged 1.23 g calcium/kg and 1.0 g phosphorus/kg. The Ca:P ratio was 1:1 in the colostrum and about 1.6:1.0 toward the end of lactation. Milk obtained from a large population had an average Ca:P ratio of 1.2:1.0. Tacui et al. (53) reported that the calcium and phosphorus content of cows' milk was 132 and 98 mg/100 ml, respectively. These levels were not related to the milk yield or the age of the cows. Eckles et al. (12) and Becker et al. (3) noted the calcium and phosphorus content of the milk was maintained at a normal concentration even in extreme shortage of phosphorus. Becker et al. (3, 4) observed that a deficiency in calcium or phosphorus lowered the milk yield, but did not affect its composition. The addition of 2% bone meal to a low-calcium ration was observed to increase milk yield, and the persistency was much greater for cows receiving the supplement.

Smith et al. (47) fed 25 dairy cows rations with Ca:P ratios of 1:1, 4:1, 8:1, 8:2, and 8:8 for 20 wk, and found no significant difference between treatments in terms of level and persistency of milk production, or total solids, ash phosphorus, calcium and vitamin A content. However, the carotene level in the milk increased as the ratio of Ca:P became wider, and was lower where cows were fed the higher levels of total phosphorus.

Smith et al. (47) pointed out that no one can deny the importance of the parathyroids in regulating the levels of calcium and phosphorus available for milk production. Stott and Smith (50) reported that parathyroidectomy during the dry period resulted in decreased milk yields in the subsequent lactation as compared with the same period during the previous lactation.

Fertility

Infertility problems where no specific infectious disease could be identified have been defined by Alderman (2) as nutritional infertility. Hignett (31) observed that breeding problems caused by mineral deficiencies or imbalances are most frequently encountered in highly productive herds. Evidence was presented for an interrelationship between calcium and phosphorus ratio and the level of manganese in the ration.

Hignett (30) surveyed 86 dairy herds, noting the relationship between various nutritional states and fertility. Usually, where there was a high intake of calcium and a low intake of phosphorus, the breeding record of the herd was poor. Where the levels of calcium and phosphorus were sufficient when viewed separately, the ratio appeared to bear some relationship to the conception rate. In most cases where there was a wide ratio of Ca:P due to excess calcium, there was herd infertility. In a few cases, the imbalance was due to the feeding of phosphorus in excess, which also seriously impaired fertility. Narrowing the Ca:P ratios for two herds increased conception rates from 30 and 25% to 70%.

Hignett and Hignett (32) found that there was a relationship between the CaO and P_2O_5 intake and fertility in dairy cattle. With an increase in phosphorus intake there was a marked increase in conception rate up to the point where animals were receiving 20 g more than the adopted standard of 23 g for maintenance and 19 g for each gallon of milk. When the phosphorus intake was low there was a tendency for fertility to drop as the amount of calcium consumption increased. On the other hand, cattle with high phosphorus and low calcium intake showed low fertility. In cows and heifers receiving less than 20 g excess P_2O_5 over the above standard, the conception rate decreased as the ratio widened, but in cattle receiving 20 g or more excess P_2O_5 the converse happened. No dairy heifers receiving less than 40 g P_2O_5 per day conceived on first service, whereas 50% of the heifers receiving more than 40 g P_2O_5 per day conceived on first service (33). Webster (59) found a higher conception rate with a $CaO:P_2O_5$ ratio more narrow than 1.32:1 than with a ratio higher than 1.32:1; however, the level of phosphorus was uniformly higher in the former group.

Hignett and Hignett (34) found that in cattle receiving a low phosphorus intake, the effect of the $CaO:P_2O_5$ ratio on fertility was apparently influenced by the vitamin D status. The conception rate decreased more markedly with a wide ratio as the vitamin D reserve became depleted during the winter period. When the vitamin D status was low an increase in phosphorus intake led to improved fertility.

After the addition of 2% bone meal to a ration considered low in calcium, Becker et al. (4) noted that the day of conception was changed from 105 to 169 days after parturition in dairy cows.

Ford (18) stated that faulty nutrition is by far the most likely cause of ovarian disfunction on a herd basis. Eckles et al. (12) observed that the highest producing cows in the herd are the ones in which suspension of ovulation occurs.

Swenson et al. (52), using Hereford heifers, reported that excess dietary calcium added to a basal ration of prairie hay, linseed meal, and iodized salt depressed the development of follicles and ovulation. When 1.5 lb of alfalfa hay were fed along with excess calcium in the above basal ration ovulation occurred; however, estrus was not observed. When each cow was fed 2 lb of alfalfa hay, the development of follicles was not depressed and estrus was observed.

Hignett and Hignett (33) fed heifers different levels of P_2O_5 ranging from 15 to 165 g. Anestrus was noted only in the group with the lowest phosphorus intake, although subestrus and irregular estrus occurred in other groups. Regular estrus was common in those groups with the highest phosphorus level. Estrus was very difficult to determine in the cattle receiving low P_2O_5 levels. Similarly, Eckles et al. (12) observed that cows on a ration low in phosphorus showed entire cessation of estrus. In a limited number of individual cases, ovarian function returned to normal following the feeding of monosodium phosphate or tricalcium phosphate.

Adams (1) suggested that the problem of weak or silent estrus in dairy cows may be corrected by proper application of the correct Ca:P ratios.

Piatkowski (44) pointed out that an intake of only 20-30 g of phosphorus per cow per day during the dry period appeared to have an adverse effect on subsequent fertility. Hignett (30) also cited other work in which a marked improvement in reproductive efficiency resulted from feeding cattle a phosphorus supplement.

Ford (18) and Hignett (30) stated that a calcium to phosphorus ratio of 1:1 appeared to be nearly ideal for high fertility, provided the actual intake of phosphorus was sufficient.

Parturient Paresis

Parturient paresis has been assumed to be the result of parathyroid insufficiency at the time of parturition (6, 27, 29). The secretion of parathyroid hormone (6) is determined by the levels of circulating blood calcium. When the blood calcium falls, the parathyroids are stimulated; when it rises, they are depressed.

Stott and Smith (51) have indicated that the parathyroid glands are quite inactive and presumably secrete a small amount of hormone in cows in heavy lactation or in cows having milk fever. The activity of the parathyroids is closely correlated to the calcium and phosphorus dietary intake of the cow, and not the fact that she is lactating (6, 49). Boda and Cole (7) thought that low Ca:P ratios activated the parathyroids and so caused mobilization of the skeletal calcium reserves. However, Pappenhagen (42) stated that parathyroid hormone did not appear to alter the rate of calcium mobilization.

The calcium intake usually is high during lactation, and the gland is correspondingly at a very low secretory level. Only at calving time does it become extremely active. Stott and Smith (51) cited recent evidence that high levels of estrogen, which is at a high level at calving time, causes bone accretion. This high activity at parturition apparently attempts to compensate for the loss of blood calcium by opposing the estrogenic effect.

Jackson et al. (35) observed that parturient cows were not responsive to parathyroid extract, and its administration just after calving had no apparent effect on the occurrence or severity of milk fever. Stott and Smith (50) found serum calcium levels were reduced by parathyroidectomy to within the range where milk fever symptoms occur, although none of the cows developed milk fever.

Hibbs and Pounden (26, 27) and Hibbs et al. (28, 29) found that the increasing blood calcium level resulting from feeding over 5 million I.U. of vitamin D seemed to be the result of a parathyroid replacement action which provided for the maintenance of higher than normal blood calcium levels during the critical postpartum period. Feeding vitamin D in the form of irradiated dry yeast and viosterol (irradiated ergosterol, 1,000,000 U.S.P. units per gram dissolved in corn oil) at the levels of 20 or 30 million I.U. resulted in 70% protection against milk fever in cows for which the calving interval was predicted with sufficient accuracy that the vitamin could be fed (26, 27). Low levels of vitamin D administration, i.e., less than 2 million I.U., did not raise calcium or phosphorus levels and thus did not prevent milk fever (24, 25, 28). The feeding of vitamin D for extended periods of time depressed parathyroid activity (27, 28).

Ward et al. (58), Ward (56), and Stott (49) reported that dairy cows which ultimately came down with milk fever had a severe negative calcium balance. Cows which did not develop milk fever maintained their calcium reserves. But, all cows were in negative calcium balance following parturition for at least 5 to 10 days.

In studies by Jackson et al. (35) it was found that milk fever can result from either low calcium level or a low level of both calcium and phosphorus. Boda and Cole (6) observed that cows which did not develop milk fever when fed a low calcium diet were affected with the condition when they received a high-calcium diet before a subsequent parturition. In contrast, Boda and Cole (6) cited reports where the feeding of high-calcium diets reduced the incidence of milk fever. Ender et al. (14)

found that the incidence of milk fever seems to increase with prolonged feeding of a ration having a high level of calcium or an imbalance of calcium and phosphorus. Feeding rations unbalanced in calcium and phosphorus during the dry period produced milk fever in cows with no previous history of the condition. Combinations of excess calcium-normal phosphorus, excess calcium-low phosphorus, and normal calcium-low phosphorus, all increased the incidence of milk fever.

Low calcium-high phosphorus diets have effectively prevented milk fever (6, 7, 56). Boda and Cole (6) reported that there appeared to be a direct correlation between the calcium phosphorus ratio of the prepartum diet and incidence of milk fever. Thus, 30% of the animals recieving a dietary Ca:P ratio of 6:1, 15% of the cows fed a dietary ratio of 1:1, and none of those fed a 1.3:3 dietary Ca:P ratio exhibited clinical symptoms of milk fever.

More recently, Stott (49) adjusted the Ca:P ratio from 3.7:1 to less than 1.5:1 and obtained a decrease in milk fever from 76% to none within 6 months. The same cows had a 56% incidence of milk fever the year following their return to the unbalanced ration. It was approximately 8 months after changing back to the unbalanced ration before a case of milk fever occurred.

In summarizing the evidence on parturient paresis, Stott (49) stated that it is the result of a lack of available dietary phosphorus during late lactation and the dry period. He also concluded that (a) the major role in controlling calcium excretion and retention in the bovine is played by phosphorus; (b) even when dietary phosphorus is adequate, excessive calcium tends to form chemical complexes with phosphorus in the digestive tract, so that it is necessary to narrow the ratio of Ca:P in the feed to obtain sufficient phosphorus absorption; (c) bone salts are reabsorbed to gain the needed phosphorus to compensate for a lack of sufficient available dietary phosphorus for metabolic processes, growth, and milk production, with the excessive calcium fraction resulting from the bone breakdown being excreted; (d) during the dry period cows are usually receiving mainly a roughage ration with a wide Ca:P ratio, so the increased need for phosphorus to build soft tissues in the dam and fetus result in bone reabsorption and puts the cows in a negative calcium balance; and (e) the continuous feeding of rations high in calcium and low in phosphorus has an accumulative effect, with the loss of bone salt resulting in milk fever at the time of parturition.

EXPERIMENTAL PROCEDURE

Experimental Animals

Eighteen Holstein dairy cows from the Oklahoma State University herd were used for the experiment. All the cows were in the second or third lactation. A randomized block design was used, with the cows paired on the basis of calving date and previous milk and fat production. From approximately 3 days pospartum until the cows were started on experiment, each cow was fed 24 lb of pelleted herd grain, 9.6 lb corn silage, and 12.8 lb hay per day. At 17 days postpartum, one member of the pair was randomly assigned to a ration having a relatively narrow ratio of calcium to phosphorus, while the other member of the pair was assigned to a ration with a relatively wide ratio of calcium to phosphorus. The data collection period was started on the Saturday coinciding with, or immediately following, the seventeenth day postpartum. The calving date, previous milk and fat production, and the ration each cow received are presented in Table I.

Management of Cows

With the exception of the time that the cows were being milked, all cows were stanchioned in the main dairy barn from 1 PM each day until 8 AM the next morning. At this time they were turned out into a large exercise lot with access to a free-stall housing barn with a southern exposure. Fresh water was available at all times from watering cups in the barn, and an automatic waterer equipped with a thermostatically

TABLE I

EXPERIMENTAL ANIMALS

Pair	Cow	Calving date	Grain mixture[a]	Previous Production Milk	Previous Production Fat
				lb	%
1	549	7/22/65	I	15,710	2.8
	538	7/23/65	II	8,280	2.7
2	532	7/28/65	I	14,120	2.5
	543	7/23/65	II	12,100	2.3
3	544	8/21/65	I	11,230	2.7
	523	8/30/65	II	13,890	2.8
4	475	8/ 4/65	I	9,410	2.8
	555	8/19/65	II	11,020	2.8
5	480	9/ 4/65	I	9,530	2.3
	560	9/11/65	II	9,640	2.2
6	511	8/20/65	I	12,530	2.2
	411	9/ 6/65	II	16,140	2.1
7	539	10/ 1/65	I	12,600	2.5
	510	9/27/65	II	15,460	2.2
8	573	11/17/65	I	12,390	2.6
	443	10/31/65	II	11,640	2.7
9	522	11/17/65	I	13,500	2.3
	432	10/ 1/65	II	14,610	2.8

[a]I = calculated Ca:P ratio of 1:6; II = calculated Ca:P ratio of 1.5:1.

controlled heating element in exercise lot.

The cows were fed their entire rations in the barn in the individual stanchions. Alfalfa hay was fed at approximately 2 AM and 1 PM, prior to feeding the grain and silage, to promote maximum hay consumption. The silage and grain rations were fed at approximately 4 AM and 4 PM each day. Metal tubs were fastened in the mangers to allow the grain to remain separated from the hay and silage.

The cows were bred at the first estrus following 35 days postpartum and at each subsequent estrus until conception. Observations for estrus were made at each milking, during feeding, and several times each day while the cows were afforded exercise during the morning. Artificial insemination was used for first and second services. If more than two services were necessary, the OSU herd bulls were used. All cows were examined by a veterinarian on the OSU staff prior to the first breeding. Pregnancy examinations via rectal palpation were performed at approximately 45 to 60 days following the last service.

Observations were made several times daily regarding the health and general condition of the cows. Diagnoses and appropriate treatment of all health problems were administered by the OSU veterinary staff.

Composition and Handling of Rations

All of the grain rations for this experiment were mixed by Stillwater Milling Company, Stillwater, Oklahoma. A pair of mixers was usually available which eliminated the chance of obtaining contamination from one experimental ration to the other. The mixers were always cleaned out with approximately 300 lb of ground sorghum grain, and if it was necessary for one experimental ration to follow the other ration in the mixing sequence, the mixer was also cleaned out between the rations. Mixing time was standardized at 5 min. The clean-outs from the mixers were used to clean out the pellet mill prior to pelleting the experimental rations. The pellet size was 3/16 inch in diameter. Brightly colored tags were attached to the feed sacks to identify the rations rapidly and accurately.

Monosodium phosphate, defluorinated rock phosphate, and calcium carbonate (Table II) were used as the mineral supplements to obtain the desired ratios of calcium to phosphorus. The large amount of phosphorus provided by monosodium phosphate was used to offset the high calcium content of the forage and thus obtain a relatively narrow ratio of the two elements in the total ration. Calcium carbonate added additional calcium to the grain mixture, resulting in a relatively wide ratio of calcium to phosphorus in the other ration. Defluorinated rock phosphate was used to balance the total phosphorus content so that both rations would contain approximately the same amount of total phosphorus. Samples were obtained from each 100 lb of grain ration, refrigerated, and later composited by 2 wk intervals for analysis. Approximately 3000 lb of the respective grain mixtures were represented in each composited grain sample.

The alfalfa hay was the first cutting from a second-year stand that had been top dressed with superphosphate. Each bale of hay was sampled, using a Penn State hay sampler, and 60-bale composites were made. These composite samples were refrigerated for later analysis.

Good quality corn silage was in storage in three upright silos at the OSU dairy barn at the beginning of the experiment. Enough silage was removed from the silos each day to maintain fresh silage for the 18

TABLE II

COMPOSITION OF PELLETED GRAIN MIXTURES

Ingredient	Mixture I[a]	Mixture II[b]	Herd mixture
	lb	lb	lb
Sorghum grain, ground	1400	1380	1400
Wheat shorts	200	200	200
Cottonseed meal	200	200	200
Urea	20	20	20
Salt	20	20	20
Vitamin-trace mineral mix	20	20	20
Molasses	120	120	120
Monosodium phosphate	20	--	--
Calcium carbonate	--	20	--
Defluorinated phosphate	--	20	20

[a]Calculated Ca:P ratio of 1:6.
[b]Calculated Ca:P ratio of 1.5:1.

experimental animals. Silage samples were collected weekly and refrigerated for later analysis. Due to the fact that there was a shortage of silage, the silage was removed from the ration after the cows had been on experiment for 16 wk.

Feed Allowances

The cows were fed a 60:40 ratio of grain to hay equivalent. The hay equivalent was divided into hay and silage on a ratio of 4:1, respectively. Three pounds of silage was used as one pound of hay equivalent.

Since all the cows consumed less than the required amount of feed during early lactation, a standard amount of concentrates and roughage was fed during the first 8 wk of the experiment. Thus, the cows received 24 lb of concentrates, 9.6 lb silage, and 12.8 lb hay per day during this period. The feed allowances for the cows which were consuming the above amounts of feed at the end of the eighth week were changed to the amount theoretically required for maintenance and milk production at this point in the experiment. The allowances for other cows were changed to the calculated requirement as feed consumption warranted. The theoretical requirement for each cow was calculated on the basis of milk production and body weight during the eighth week on experiment and the feed allowance was reduced by 5% of the original theoretical requirement every 4 wk. The total digestible nutrient (TDN) requirement for each cow was based on a grain feeding schedule given by Stone et al. (48), in which 2 lb hay equivalent (good forage) per 100 lb body weight was assumed for cows producing 3% milk. Assuming that hay of this quality would contain 50% TDN and that a typical grain mixture would contain 70% TDN, the TDN requirement for each cow was calculated. Sixty-eight per cent of this TDN requirement was fed as the grain ration and 32% was fed as hay equivalent.

Collection of Data and Analyses

The feed allowance for each cow was divided into two equal portions and fed at the times indicated above. The refused feed was weighed back each morning while the cows were in the exercise lot.

Duplicate samples of concentrates, hay, and silage were weighed into either tared curcibles or aluminum foil containers and dried at 100 C in a constant temperature oven for approximately 12 hr. They were then weighed and the per cent dry matter calculated. All of the feed samples were ground using a Wiley mill with a 1 mm sieve.

The dried samples were ashed at 600 C in a Hoskins Electric Muffle oven for 10 to 12 hr. The ash was dissolved in 1:3 HCl (1 part HCl to 3 parts distilled water) and transferred to either a 25 or 50 ml volumetric flask and made up to volume with distilled water. This volume was divided into two portions, one for calcium analysis and the other for phosphorus analysis. Total phosphorus was determined by the procedure outlined by Fiske and Subbarow (16), using a Klett-Summerson colorimeter (Model No. 1019).

The calcium content was determined by using the procedure outlined by Willis (60) using a Perkin Elmer 303 atomic absorption spectrophotometer.

Body weights were recorded on the fifteenth through the seventeenth day postpartum and then for three consecutive days at 4-wk intervals for the duration of the experiment.

Milk yield was recorded twice daily and milk samples were taken in individual bottles at four consecutive milkings each week for the first 7 months postpartum. The following analyses were performed on the milk: (a) milk fat, using the Babcock procedure; (b) protein, using the Kjeldahl procedure; and (c) total solids, by drying for 4 hr in a Stable-Therm forced air oven at 100 C.

Blood samples were taken monthly for serum calcium and phosphorus analyses. Blood was collected from the jugular vein and allowed to coagulate. The blood clot was broken lose from the wall of the test tubes with a small wire and the samples centrifuged at approximately 4000 g for 10 minutes. The serum calcium and inorganic phosphorus were determined by the procedures outlined by Willis (60) and Fiske and Subbarow (16), respectively.

RESULTS AND DISCUSSION

Feed Consumption

The average daily consumption of dry matter for the initial 16 wk of the experiment covered in this report was 33.8 and 32.3 lb/day for Groups I and II, respectively. The average consumption of the grain ration, silage, and hay all increased as the experiment progressed (Table III). This trend was exhibited by all cows in Group I and by 7 cows in group II (Table IX). One cow in the latter group decreased in dry matter consumption while the intake of the other one remained relatively constant.

The increase in dry matter consumption was attributed to the fact that at the beginning of the experiment none of the cows consumed the allotted amount of concentrate, hay, and silage. As time progressed, feed consumption increased to the point that the standard amounts offered during the first 8 wk were consumed by the majority of the cows by the end of this period. After 8 wk on the experiment, or at a subsequent time when the cows were consuming the standard amount of feed, the feed allowance was changed to the amount needed to meet the theoretical TDN requirement for maintenance and milk production. In nearly all instances, the amount of feed needed to meet the theoretical TDN requirement was higher than the amount the cows had been receiving. The cows did not consume all of the feed offered them at this point, but feed consumption gradually increased as the experiment progressed.

TABLE III

AVERAGE DRY MATTER CONSUMPTION BY WEEKS ON EXPERIMENT

Week on experiment	Group I (narrow Ca:P ratio)				Group II (wide Ca:P ratio)			
	Grain	Hay	Silage	Total	Grain	Hay	Silage	Total
	(lb/wk)				(lb/wk)			
1	145.9	39.0	16.4	201.3	141.6	40.0	14.7	196.3
2	143.2	48.3	15.9	207.4	140.1	41.2	15.4	196.7
3	146.6	56.9	17.0	220.5	145.3	48.0	17.6	210.9
4	145.4	52.5	18.3	216.2	143.3	52.0	17.6	212.9
5	148.4	57.6	17.3	223.3	145.5	52.8	18.5	216.8
6	146.5	62.1	17.6	226.2	140.0	57.1	17.8	214.9
7	148.5	65.3	19.2	233.0	144.7	58.3	18.6	221.6
8	150.3	66.8	19.9	237.0	146.5	62.3	19.5	228.3
9	156.7	69.7	19.6	246.0	153.0	65.4	18.8	237.2
10	151.5	73.8	20.0	245.3	150.1	64.1	18.4	232.6
11	159.4	69.9	22.9	252.2	152.6	68.1	18.6	239.3
12	160.3	70.9	22.0	253.2	152.2	68.1	19.0	239.3
13	159.1	71.4	20.6	251.1	153.2	69.6	19.6	242.4
14	159.5	71.2	20.5	251.2	153.0	68.5	18.4	239.9
15	166.7	71.5	20.3	258.5	153.5	70.6	16.8	240.9
16	171.7	76.0	20.8	268.5	153.4	73.3	16.8	243.5

There was a tendency for the cows to consume a greater proportion of the concentrate and silage than the hay, even though the latter was offered first at each feeding. Failure to consume all of the feed during the early part of the experiment was attributed to the fact that the amount fed exceeded the body capacity of the cows.

The first cows were started on the experiment in August, and consumed approximately 50% of the hay they were offered. This was attributed to the warm weather during August and September. The summer freshening cows did not consume the standard amount of feed offered until they were on experiment for approximately 3 months, whereas, the cows freshening later in the fall when the weather was cooler consumed nearly all the feed offered them by approximately 1 month after going on experiment.

Calcium and Phosphorus Intake

The average weekly consumption of calcium and phosphorus for the 16 wk was 1.56 and 1.50 lb, respectively, for Group I, and 2.56 and 1.37 lb, respectively, for Group II. The calculated Ca:P ratios were 1.22:1 and 2.37:1 for Group I and II, respectively, with the phosphorus level at approximately 0.4%. However, the average Ca:P ratios for the rations actually consumed was 1.04:1 for Group I and 1.88:1 for Group II. The average calcium and phosphorus intake by weeks on experiment is presented in Table IV. There is some variation in the ratio of Ca:P among the weeks. This variation is partly due to the fact that the cows did not consume all of the feed offered. The complete consumption of the allotted amounts of concentrate, silage, and hay would have given a nearly constant Ca:P ratio for the duration of the experiment. Variations in the calcium and phosphorus content of the feeds also contributed to

TABLE IV

AVERAGE CALCIUM AND PHOSPHORUS INTAKE BY WEEKS ON EXPERIMENT

Week on experiment	Group I[a]			Group II[a]		
	Calcium	Phosphorus	Ca:P	Calcium	Phosphorus	Ca:P
	(1b)	(1b)		(1b)	(1b)	
1	1.00	1.38	0.72:1	2.77	1.35	2.05:1
2	1.08	1.37	0.79:1	2.48	1.33	1.86:1
3	1.28	1.40	0.91:1	2.58	1.35	1.91:1
4	1.35	1.40	0.96:1	2.64	1.33	1.98:1
5	1.80	1.44	1.25:1	2.56	1.34	1.91:1
6	1.81	1.45	1.25:1	2.54	1.32	1.92:1
7	1.69	1.47	1.15:1	2.52	1.36	1.85:1
8	1.70	1.46	1.16:1	2.48	1.36	1.82:1
9	1.62	1.49	1.09:1	2.58	1.42	1.82:1
10	1.72	1.55	1.11:1	2.51	1.35	1.86:1
11	1.51	1.58	0.96:1	2.64	1.39	1.90:1
12	1.46	1.54	0.95:1	2.39	1.39	1.72:1
13	1.51	1.71	0.88:1	2.57	1.36	1.89:1
14	1.58	1.52	1.04:1	2.61	1.35	1.93:1
15	1.86	1.57	1.18:1	2.55	1.42	1.80:1
16	2.03	1.63	1.25:1	2.61	1.43	1.83:1

[a]Group I = Narrow Ca:P ratio; Group II = Wide Ca:P ratio.

the variation in the actual ratios of the two elements in the feed consumed. This was particularly true with regard to the calcium content of the silage, which ranged from 0.16 to 2.07% on a dry matter basis.

Also, there apparently was a mistake in labeling the grain mixtures at the time of mixing on one occasion so that the cows received the wrong grain mixtures for a period of about 3 wk. With the variation in calving dates, this mistake occurred from 1 to 5 months after the different cows were started on experiment, and, therefore, was not reflected in the average Ca:P ratios of the rations consumed during different weeks during the experiment (Table IV).

Blood Levels of Calcium and Phosphorus

There did not appear to be any appreciable difference between groups with respect to either blood serum calcium or inorganic phosphorus levels (Tables V and VI). The levels of both calcium and phosphorus remained relatively constant throughout the experiment.

The values for blood inorganic phosphorus obtained in this experiment are approximately 2-4 mg/100 ml higher than the values obtained by Harshberger (37) and Payne and Leech (43). However, the calcium values reported by these workers are in agreement with the values obtained in this study.

The lack of any appreciable difference in blood phosphorus levels is in agreement with work by Dowe et al. (11) with steers fed Ca:P ratios of 1.3:1, 4.3:1, 9.1:1, and 13.7:1 and Swenson et al. (52) with beef heifers fed Ca:P ratios as wide as 10:1. However, Smith et al. (47) observed the total blood phosphorus level in dairy cows to decline as the Ca:P ratio changed from 1:1 to 8:1. However, the total level of

TABLE V

BLOOD CALCIUM LEVELS BY INDIVIDUAL COWS

Pair No.	Month on experiment 1	2	3	4	5	6	7	8	9
	(mg/100 ml)								
Group I[a]									
1	--	--	--	11.3	11.0	11.8	10.9	11.1	11.0
2	--	--	--	10.5	10.3	11.6	10.5	10.4	12.7
3	--	--	11.3	11.6	12.4	10.9	10.4	11.1	
4	--	--	10.3	10.9	11.2	11.6	10.3	10.4	
5	--	10.8	11.7	11.3	10.4	11.2	11.7		
6	--	--	11.1	11.5	11.5	12.2	9.7	11.8	
7	11.4	10.5	10.5	10.3	10.2	12.1			
8	10.6	11.3	10.8	11.8	12.8				
9	11.6	11.2	9.9	11.0	12.2				
Avg.	11.2	10.9	10.8	11.4	11.3	11.6	10.6	11.0	11.9
Group II[a]									
1	--	--	--	11.7	11.8	11.2	10.2	12.2	11.2
2	--	--	--	10.8	11.2	10.5	10.7	11.7	10.9
3	--	11.8	11.1	10.9	9.8	11.5	11.3		
4	--	--	11.4	10.8	11.2	11.5	10.8	11.2	
5	--	11.0	11.1	11.7	10.8	11.5	10.5		
6	--	10.4	11.2	11.8	10.4	9.8	9.8		
7	10.5	11.1	11.2	10.4	9.8	11.5			
8	10.8	9.9	10.2	10.3	11.0				
9	11.0	11.2	12.1	10.1	9.6	10.9			
Avg.	10.8	10.9	11.2	10.9	10.6	11.0	10.5	11.7	11.1

[a]Group I = Narrow Ca:P ratio; Group II = Wide Ca:P ratio.

TABLE VI

BLOOD PHOSPHORUS LEVELS BY INDIVIDUAL COWS

Pair No.	Month on experiment								
	1	2	3	4	5	6	7	8	9
	(mg/100 ml)								
Group I[a]									
1	---	---	---	6.2	7.6	7.4	8.9	6.5	6.8
2	---	---	---	6.1	8.6	8.3	9.1	9.3	9.9
3	---	---	7.0	7.3	6.9	7.1	7.9	7.7	
4	---	---	7.0	9.0	7.9	8.8	7.4	8.5	
5	---	4.7	8.6	7.9	7.2	9.9	9.7		
6	---	---	6.8	5.1	6.5	8.4	7.4	7.5	
7	6.2	8.1	8.5	9.1	6.7	7.8			
8	7.5	5.8	8.6	7.9	8.0				
9	10.3	7.8	10.4	7.8	9.2				
Avg.	8.0	6.6	8.1	7.4	7.6	8.3	8.4	7.9	8.3
Group II[a]									
1	---	---	---	7.5	7.1	7.7	8.8	9.0	8.0
2	---	---	---	5.0	7.5	6.8	8.5	7.8	9.4
3	---	6.8	5.8	7.8	8.7	7.0	9.1		
4	---	---	6.8	8.5	6.5	6.1	6.4	7.1	
5	---	6.1	9.2	6.7	6.5	6.6	6.1		
6	---	5.8	7.9	7.0	8.6	8.2	7.7		
7	5.3	5.6	6.5	6.8	6.6	7.3			
8	5.0	7.5	6.8	8.5	7.8	7.7			
9	4.8	9.1	8.1	6.9	5.3	8.1			
Avg.	5.1	6.8	7.3	7.2	7.2	7.3	7.7	8.0	8.7

[a]Group I = Narrow Ca:P ratio; Group II = Wide Ca:P ratio.

phosphorus in the diet appeared to have a greater influence on the level of blood phosphorus than did the Ca:P ratio.

Milk Production and Weight Changes

The cows in Group I produced slightly more total milk during the 16 wk than did the cows in Group II; however, the cows in Group I started production at a higher level and slowly decreased to the twelfth week after which both groups produced at the same level (Table VII). The average fat percentage for the cows in Group II was slightly higher during the first 6 wk so that the total pounds of fat produced was very similar for both groups. There was no apparent difference between the two groups in protein or total solids per cent. These results agreed with those of Smith et al. (47) who fed dairy cows Ca:P ratios of 1:1, 4:1, 8:1, 8:2 and 8:8 for 20 wk and found no significant difference between treatments in terms of level and persistency of milk production or total solids. Body weight changes were similar for both groups.

Reproductive Performance

The average number of days from calving to first estrus and from calving to first service was 49.2 and 62.9 for Group I, and 48.4 and 52.6 for Group II, respectively (Table VIII). The small difference between the days from calving to first estrus, and from calving to first service was not considered to be of any practical significance.

The number of days from calving to conception was 85.0 ± 47.6 (standard deviation) for Group I, and 121.9 ± 52.9 for Group II. The difference between the two groups was not statistically significant ($P > .05$). The average number of services per conception was 1.66 ± 1.0 (standard deviation) for Group I and 3.00 ± 1.6 for Group II. The

TABLE VII

MILK YIELD AND COMPOSITION BY WEEKS ON EXPERIMENT

Response criteria	Group	Week on experiment 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Milk, lb	I	474	468	471	464	454	433	446	435	419	391	391	373	368	366	356	345
	II	422	405	420	400	402	394	395	390	381	376	362	372	357	338	350	341
Protein, %	I	2.8	2.9	2.8	2.8	2.8	2.9	3.0	3.1	3.0	3.2	3.2	3.2	3.2	3.2	3.2	3.2
	II	3.0	2.7	2.9	2.9	2.9	3.0	3.0	3.1	3.2	3.1	3.2	3.1	3.2	3.2	3.3	3.3
Total Solids, %	I	11.1	11.3	11.4	10.8	10.8	11.2	10.9	10.8	10.8	10.7	10.7	10.8	10.9	11.1	11.1	10.9
	II	11.7	11.7	11.4	11.2	11.2	11.3	11.1	11.0	11.0	12.2	11.1	11.3	11.2	11.1	11.1	11.3
Fat, %	I	2.6	2.7	2.8	2.5	2.3	2.4	2.3	2.0	2.1	1.8	1.8	1.9	2.1	2.3	2.2	2.1
	II	3.0	3.1	2.7	2.6	2.5	2.5	2.5	2.3	2.3	2.3	2.1	2.2	2.3	2.2	2.2	2.2

[a]Group I = Narrow Ca:P ratio; Group II = Wide Ca:P ratio.

TABLE VIII

REPRODUCTIVE PERFORMANCE BY INDIVIDUAL COWS

Pair No.	Days from calving to first estrus	Days from calving to first service	Days from calving to conception	No. of services per conception	Estrus cycles after 35 days postpartum, days
Group I[a]					
1	86	86[b]	194	4	31, 32, 45
2	34	85	108	2	51,[c] 23
3	28	54[d]	102	2	9, 17,[c] 48
4	86	86	86	1	
5	25	48	68	2	23,[c] 20
6	74	74	74	1	
7	46	46	46	1	
8	15	38	38	1	23[c]
9	49	49	49	1	
Avg.	49.2	62.9	85.0	1.66	
Group II[a]					
1	41	41[e]	168	6	23,[c] 27, 22, 9, 22, 24
2	68	68	117	3	24, 25
3	43	43	64	2	21
4	41	41	41	1	
5	68	68	199	3	81, 50
6	66	66	149	3	21, 41,[f] 21
7	37	37	88	2	51
8	55	55	168	5	22, 22, 24, 45
9	17	54	103	2	37,[c] 49
Avg.	48.4	52.6	121.9	3.00	

[a]Group I = Narrow Ca:P ratio; Group II = Wide Ca:P ratio.
[b]Examined by veterinarian and believed to be in heat and was bred.
[c]First service occurred when estrus was exhibited at the end of this cycle.
[d]Was not bred at previous estrus because it was an extremely short cycle.
[e]Was not bred at first estrus following 35 days due to management error.
[f]Treated for cystic ovaries and was not bred.

difference between groups was statistically significant ($P < .05$); however, interpretation of these results involved consideration of several factors which could have a bearing on the reproductive performance of the cows in the two groups.

The cow in Pair 8 of Group II had calving difficulty and developed a serious uterine infection so that the data collected on this cow may not be valid. If one eliminated this cow and her pair mate, the average number of days from calving to conception would be 90.9 and 116.1 days for Group I and II, respectively. The average number of services per conception would be 1.75 and 2.86 for Group I and II, respectively. Similarly, elimination of Pair 1, involving cows with an unusually large number of services, in addition to Pair 8, would leave 1.4 and 2.3 services per conception for Group I and II, respectively. Thus, the difference between groups was not believed to be attributable to a few individual cows with breeding difficulty.

There was quite a variation in the length of estrous cycles, ranging from 20 to 51 days in Group I and 9 to 81 days in Group II. This was an indication that several silent estrus periods occurred or else estrus was not observed in some instances. The latter may account for some of the long intervals since the cows were stanchioned in the barn 19 hr of each day, which did not leave much time for estrus observation.

SUMMARY AND CONCLUSIONS

Eighteen Holstein cows, in their second and third lactations, were used to study the effects of different Ca:P ratios on lactating dairy cows. The cows were paired on the basis of production level and calving date, and one member of each pair was fed a ration with a Ca:P ratio of 1.04:1, whereas the other member received a ration with a Ca:P ratio of 1.88:1. This report covers the initial 16 wk of the experiment which started at approximately 17 days postpartum. The response criteria were body weight changes, milk yield and composition, blood level of calcium and phosphorus, reproductive performance and general health of the cows.

There were no appreciable differences between the groups with respect to blood serum calcium and inorganic phosphorus, body weight changes, and milk yield and composition. The average number of services required per conception was 1.66 ± 1.0 (standard deviation) for the cows receiving the 1.04:1 Ca:P ratio, and 3.00 ± 1.6 for the group receiving the 1.88:1 ratio. The difference between groups was statistically significant ($P < .05$). However, no significant differences between groups were observed with respect to average number of days from calving to first estrus, first service or conception, or with respect to length of estrous cycles.

LITERATURE CITED

(1) Adams, R. 1964. What's New for Dairy. Successful Farming, 62(5): 29.

(2) Alderman, G. 1963. Mineral Nutrition and Reproduction in Cattle. Vet. Record, 75: 1015.

(3) Becker, R. B., Eckles, C. H. and Palmer, L. S. 1927. Effect of Mineral Deficiency on the Yield and Composition of Cow's Milk. J. Dairy Sci., 10: 169.

(4) Becker, R. B., Neal, W. M., Shealy, A. L. 1933. Effect of Calcium Deficient Roughages Upon Milk Production and Welfare of Dairy Cows. Florida Agr. Sta. Tech. Bull., 262.

(5) Blosser, T. H., and Smith, V. R. 1950. Parturient Paresis. V. Blood Serum Levels of Citric Acid and Calcium in Normal Parturient Cows With Parturient Paresis. J. Dairy Sci., 33: 81.

(6) Boda, J. M., and Cole, H. H. 1954. The Influence of Dietary Calcium and Phosphorus on the Incidence of Milk Fever in Dairy Cattle. J. Dairy Sci., 37: 360.

(7) Boda, J. W., and Cole, H. H. 1956. Studies on Parturient Paresis in Cattle. Ann. N. Y. Acad. Sci., 64: 370.

(8) Calovos, N. F., Keener, H. A., and Davis, H. A. 1957. The Effects of Adequate and Excessive Calcium When Fed With Adequate Phosphorus in Growing Rations for Beef Calves. J. Animal Sci., 41: 676.

(9) Conrad, H. R., Hansard, S. L. 1957. Effects of Massive Doses of Vitamin D on Physiological Behavior of Calcium in Cattle. J. Appl. Physiol., 10: 98.

(10) Conrad, H. R., Hansard, S. L., Hibbs, J. W. 1956. Studies on Milk Fever in Dairy Cows. V. The Effect of Massive Oral Doses of Vitamin D on Absorption, Excretion, Retention and Blood Levels of Calcium and Phosphorus. J. Dairy Sci., 39: 1697.

(11) Dowe, T. W., Matsushima, J., Arthaud, V. H. 1957. The Effects of Adequate and Excessive Calcium When Fed With Adequate Phosphorus in Growing Rations for Beef Calves. J. Animal Sci., 16: 811.

(12) Eckles, C. H., Becker, R. B., and Palmer, L. S. 1926. A Mineral Deficiency in Rations of Cattle. Minnesota Agr. Exp. Sta. Bull., 229.

(13) Ellenberger, H. G., Newlander, J. A., and Jones, C. H. 1931. Calcium and Phosphorus Requirements of Dairy Cows. Vermont Agr. Expt. Sta. Bull., 331.

(14) Ender, F., Dishington, I. W., Helgebostad, A. 1956. Parturient Paresis and Related Forms of Hypocalcemic Disorders Induced Experimentally in Dairy Cows. Nord. Vet. Med., 8: 507.

(15) Fish, P. A. 1929. The Physiology of Milk Fever. III. The Blood Phosphates and Calcium. Cornell Vet., 19: 147.

(16) Fiske, C. H., and Subbarow, Y. 1925. The Colorimetric Determination of Phosphorus. J. Biol. Chem., 66: 375.

(17) Forbes, E. B., and Beagle, F. M. 1916. The Mineral Metabolism of a Milch Cow. Ohio Agr. Expt. Sta. Bull., 295.

(18) Ford, C. M. 1956. Nutritional Factors and Bovine Infertility in the East Midlands. British Vet. J., 112: 177.

(19) Greig, J. R. 1930. Studies in the Prevention of Milk Fever. Vet. Record., 10: 301.

(20) Halse, K. 1958. Apparent Strengthening of Calcium Homeostasis in Cows by Starvation of Short Duration. Nord. Vet. Med., 10: 9.

(21) Hansard, S. L., Comar, C. L., and Davis, G. K. 1954. Effects of Age Upon the Physiological Behavior of Calcium in Cattle. Am. J. Physiol., 177: 383.

(22) Hansard, S. L., Comar, C. L., and Plumlee, M. P. 1954. The Effects of Age Upon Calcium Utilization and Maintenance Requirements in the Bovine. J. Animal Sci., 13: 25.

(23) Hibbs, J. W., and Conrad. H. R. 1966. Re-Evaluation of Nutrient Allowances for High-Producing Cows. II. Calcium, Phosphorus, and Vitamin D. J. Dairy Sci., 49: 243.

(24) Hibbs, J. W., Krauss, W. E., Monroe, C. F., and Sutton, T. S. 1946. Studies on Milk Fever in Dairy Cows. I. The Possible Role of Vitamin D in Milk Fever. J. Dairy Sci., 29: 617.

(25) Hibbs, J. W., Krauss, W. E., Pounden, W. D., Monroe, C. F., and Sutton, T. S. 1946. Studies on Milk Fever in Dairy Cows. II. The Effects of Vitamin D on Some of the Blood Changes in Normal and Milk Fever Cows at Parturition. J. Dairy Sci., 29: 767.

(26) Hibbs, J. W., and Pounden, W. D. 1951. Recent Development in the Use of Vitamin D in the Prevention of Milk Fever in Dairy Cattle. J. Dairy Sci., 34: 498.

(27) Hibbs, J. W., and Pounden, W. D. 1955. Studies on Milk Fever in Dairy Cows. IV. Prevention by Short-Time, Prepartum Feeding of Massive Doses of Vitamin D. J. Dairy Sci., 38: 65.

(28) Hibbs, J. W., Pounden, W. D., and Krauss, W. E. 1947. Further Studies on the Effect of Vitamin D and of Parathyroid Extract, Parvidin, on the Blood Changes of Normal and Milk Fever Cows at Parturition. J. Dairy Sci., 30: 564.

(29) Hibbs, J. W., Pounden, W. D., and Krauss, W. E. 1951. Studies on Milk Fever in Dairy Cows. III. Further Studies on the Effect of Vitamin D on Some of the Blood Changes at Parturition and the Composition of Colostrum in Normal and Milk Fever Cows. J. Dairy Sci., 34: 855.

(30) Hignett, S. L. 1950. Factors Influencing Herd Fertility in Cattle. Vet. Record, 62: 652.

(31) Hignett, S. L. 1959. Some Nutritional and Other Inter-Acting Factors Which May Influence the Fertility of Cattle. Vet. Record, 71: 247.

(32) Hignett, S. L., and Hignett, P. G. 1951. The Influence of Nutrition on Reproductive Efficiency in Cattle. I. The Effect of Calcium and Phosphorus Intake on the Fertility of Cows and Heifers. Vet. Record, 63: 603.

(33) Hignett, S. L., and Hignett, P. G. 1952. The Influence of Nutrition on Reproductive Efficiency in Cattle. II. The Effect of the Phosphorus Intake on Ovarian Activity and Fertility of Heifers. Vet. Record, 64: 203.

(34) Hignett, S. L., and Hignett, P. G. 1953. The Influence of Nutrition on Reproductive Efficiency in Cattle. III. The Influence of Vitamin D Status on the Effect of Calcium and Phosphorus Intake on the Fertility of Cows and Heifers. Vet. Record, 65: 21.

(35) Jackson, H. D., Pappenhagen, A. R., Geotsch, G. D., and Noller, C. H. 1962. Effect of Parathyroid Hormone on Calcium and Other Plasma Constituents of Dairy Cattle Near Parturition. J. Dairy Sci., 45: 897.

(36) Keller, A. 1961. Studies on the Calcium Balance in Dairy Cows. Roczn. Nauk. rol. (Series Zootechniczna), 78:231. / Dairy Sci. Abstrs., 24: 565. 1962./

(37) Kendall, K. A., Harshbarger, K. E. 1963. Comparison of the Mineral Levels in Parturient Paretic Cows, at Parturition and During Lactation. J. Dairy Sci., 46: 635.

(38) Kleiber, M., Smith, A. H., Ralston, N. P., and Black, A. L. 1951. Padiophosphorus (P^{32}) As a Tracer for Measuring Endogenous Phosphorus in Cows Feces. J. Nutrition. 45: 253.

(39) Lenkett, W., Gimmler, W., Sieck, K. H. 1959. Calcium and Phosphorus Secretion in Milk in the Course of Lactation in Cows and Sows. Arch. Tierernahr., 9: 166. / Dairy Sci. Abstrs., 21: 425. 1959./

(40) Lueker, C. E., and Lofgreen, G. P. 1961. Effects of Intake and Calcium to Phosphorus Ratio on Absorption of These Elements by Sheep. J. Nutrition. 74: 233.

(41) Luick, J. R., Boda, J. M., and Kleiber, M. 1957. Parturition of Calcium Metabolism in Dairy Cows. J. Nutrition. 61: 597.

(42) Pappenhagen, A. R. 1960. Parathyroid Hormone and Parturient Paresis in Dairy Cattle. Dairy Sci. Abstrs., 22: 294.

(43) Payne, J. M., Leech, F. B. 1964. Factors Affecting Plasma Calcium and Inorganic Phosphorus Concentrations in the Cow With Particular Reference to Pregnancy Lactation and Age. Brit. Vet. J., 120: 385.

(44) Piatkowski, B. 1962. Study of Metabolism in High-Yielding Cows During Dry Period and Lactation. 2. Calcium and Phosphorus Metabolism. Arch. Tierernahr., 12: 75 / Dairy Science Abstrs., 25: 385. 1963./

(45) Reid, J. T. 1962. Re-examination of the Calcium Requirements of Dairy Cows. Proc. 1962. Cornell Nutrition Conf. for Feed Manufacturers.

(46) Richter, K., and Oslage, H. J. 1959. The Nutrition of High Yielding Cows. Studies of the Metabolism of Dairy Cows. Part 5. Mineral Balance in Long Term Trials During Lactation Under Different Conditions of Management. Arch. Tierernahr., 9: 166. / Dairy Sci. Abstrs., 22: 128. 1960./

(47) Smith, A. M., Holck, G. L., and Spafford, H. B. 1966. Re-evaluation of Nutrient Allowances for High Producing Cows: Calcium, Phosphorus, and Vitamin D. J. Dairy Sci., 49: 239.

(48) Stone, J. B., Spalding, R. W., Merrill, W. G., and Reid, J. T. 1964. A Dairy Cattle Feeding Program for High Production. Proc. 1964 Cornell Nutrition Conference for Feed Manufacturers.

(49) Stott, G. H. 1966. Supplemental Phosphorus to Reduce Milk Fever. Animal Nutrition and Health. January. 21: 11.

(50) Stott, G. H. and Smith, V. R. 1957. Parturient Paresis. VIII. Results of Parathyroidectomy of Cows. J. Dairy Sci., 40: 897.

(51) Stott, G. H., and Smith, V. R. 1964. Histology, Cytology, and Size of the Parathyroid in Bovine Related to Age and Function. J. Dairy Sci., 47: 426.

(52) Swenson, M. J., Goetsch, D. D., Undergijerg, G.K.L. 1962. Effects of Dietary Trace Minerals, Excess Calcium, and Various Roughages on the Hemogram Tissues and Estrous Cycles of Hereford Heifers. Am. J. Vet. Res., 23: 803.

(53) Tacui, A., Popescu, F. R., Nedelniuc, V., and Petcu, D. 1960. Variations in Calcium and Phosphorus Content of Blood and Milk of Red Dairy Cattle. Lucr. sti. Inst. Cercit. Zooteb., 18: 141 / Dairy Sci. Abstrs., 23: 344. 1961 /

(54) Visek, W. J., Barnes, L. L., and Loosli, J. K. 1952. Calcium Metabolism in Lactating Goats as Studied with Ca-45 Following Oral and Intravenous Administration. J. Dairy Sci., 35: 783.

(55) Waldern, D. E. 1965. Dietary Ca:P Ratios for Lactating Dairy Cows. Animal Nutrition and Health. December. 20: 9.

(56) Ward, G. M. 1956. Calcium Balances and Changes of Some Blood and Urinary Constituents as Related to Parturient Paresis in Dairy Cows. Ann. N. Y. Acad. Sci., 64: 361.

(57) Ward, G. M. 1959. Effect of Soil Fertility Upon the Yield and Nutritive Value of Forages. A Review. J. Dairy Sci., 42: 277.

(58) Ward, G. M., Blosser, T. H., and Adams, M. F. 1952. The Relation of Prepartal and Post-partal Mineral Balances to the Occurrence of Parturient Paresis in Dairy Cows. J. Dairy Sci., 35: 587.

(59) Webster, W. M. 1932. Bovine Sterility in New Zealand. Aust. Vet. J. 8: 199.

(60) Willis, J. B. 1960. The Determination of Metals in Blood Serum by Atomic Absorption Spectroscopy. I. Calcium Spectrochimica Acta., 16: 259.

(61) Wilson, L. T., and Hart, E. B. 1932. The Chemistry of the Blood of Dairy Cows Before and After Parturition and its Relation to Milk Fever. J. Dairy Sci., 15: 116.

A P P E N D I X E S

TABLE IX

TOTAL DRY MATTER CONSUMPTION BY INDIVIDUAL COWS

Pair No.	Week on experiment 1	2	3	4	5	6	7	8
	(lb/wk)							
Group I[a]								
1	188	156	201	178	176	204	223	235
2	199	196	223	218	213	223	232	242
3	185	176	222	226	232	230	223	231
4	153	177	181	172	211	213	231	234
5	223	233	228	229	235	238	231	240
6	190	210	219	221	220	229	232	233
7	224	237	222	225	233	242	246	243
8	223	236	243	246	248	248	248	247
9	227	245	246	229	242	208	231	239
Avg.	200	206	220	216	223	226	233	238
Group II[a]								
1	183	181	203	204	197	192	204	222
2	162	142	181	157	176	159	178	207
3	217	224	240	232	222	226	230	237
4	185	195	215	229	234	232	232	235
5	213	205	211	210	215	216	226	221
6	191	180	171	191	210	213	198	211
7	221	221	221	233	231	230	244	224
8	164	184	216	225	218	217	240	245
9	231	237	238	234	247	249	242	250
Avg.	196	197	211	213	217	215	222	228

[a]Group I = Narrow Ca:P ratio; Group II = Wide Ca:P ratio

TABLE IX (Continued)

Pair No.	Week on experiment							
	9	10	11	12	13	14	15	16
	(lb/wk)							
Group I[a]								
1	233	233	230	225	203	214	212	232
2	242	235	242	231	243	246	250	295
3	223	238	238	237	215	232	239	233
4	233	237	237	238	236	242	305	300
5	243	268	289	287	294	268	259	267
6	225	237	227	237	261	255	252	255
7	276	207	247	258	246	228	243	249
8	266	263	280	292	288	293	295	297
9	272	291	281	274	274	284	272	287
Avg.	246	245	252	253	251	251	259	268
Group II[a]								
1	236	224	223	233	238	217	232	241
2	187	173	193	191	187	201	188	204
3	230	238	243	235	245	258	265	267
4	237	231	227	223	224	218	224	224
5	216	206	211	218	205	212	208	211
6	223	230	236	237	262	254	267	270
7	229	228	222	220	213	217	211	205
8	285	258	285	271	287	271	282	283
9	291	305	314	323	321	313	291	284
Avg.	237	233	239	239	242	240	241	243

[a]Group I = Narrow Ca:P ratio; Group II = Wide Ca:P ratio.

TABLE X

TOTAL MILK PRODUCTION BY INDIVIDUAL COWS

Pair No.	Week on experiment							
	1	2	3	4	5	6	7	8
	(lb/wk)							
Group I[a]								
1	436	381	411	382	337	386	418	434
2	433	435	453	460	438	411	452	451
3	376	385	389	415	411	381	361	346
4	471	498	480	443	468	484	484	507
5	488	495	488	465	440	415	450	419
6	461	437	476	469	444	423	422	391
7	446	439	428	415	402	391	399	368
8	554	496	465	520	518	495	484	447
9	608	649	650	610	626	517	547	554
Avg.	474	468	471	464	454	433	446	435
Group II[a]								
1	467	455	442	416	389	362	382	370
2	330	285	315	287	281	268	324	332
3	470	411	413	428	388	389	388	399
4	414	367	415	409	374	359	342	326
5	422	415	402	378	355	343	324	333
6	500	474	463	460	511	491	504	459
7	375	360	345	330	315	302	288	284
8	372	514	528	533	554	551	562	562
9	449	362	462	359	450	481	446	447
Avg.	422	405	420	400	402	394	395	390

[a]Group I = Narrow Ca:P ratio; Group II = Wide Ca:P ratio.

TABLE X (Continued)

Pair No.	Week on experiment							
	9	10	11	12	13	14	15	16
	(lb/wk)							
Group I[a]								
1	400	388	389	330	325	365	324	324
2	423	423	436	409	395	407	397	371
3	352	337	319	287	291	269	263	259
4	477	463	412	416	412	402	412	366
5	415	368	384	373	364	341	351	359
6	391	246	288	320	320	309	280	275
7	351	336	326	302	287	288	271	279
8	456	446	457	451	440	433	425	410
9	515	516	515	469	482	478	482	469
Avg.	419	391	391	373	368	366	356	345
Group II[a]								
1	393	378	360	366	345	275	286	281
2	303	276	301	282	277	288	304	295
3	343	368	367	393	381	375	368	374
4	299	293	278	284	268	255	249	235
5	345	331	305	342	317	309	333	303
6	462	485	455	478	458	438	482	451
7	290	270	265	240	227	210	213	211
8	549	534	516	514	494	476	480	476
9	443	455	426	451	452	416	435	445
Avg.	381	376	362	372	357	338	350	341

[a]Group I = Narrow Ca:P ratio; Group II = Wide Ca:P ratio.

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