Milk Production and Reproductive Performance of Dairy Cows Fed Two Concentrations of Phosphorus for Two Years[1]

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ABSTRACT

The performance of lactating Holstein cows in response to P supplementation was determined in a 2-yr study. Each year included confinement feeding for approximately the first two-thirds of lactation and grazing for the remaining one-third of lactation. In yr 1, 42 cows were assigned at calving to a low or high P diet within parity. Fourteen cows from the low P group and 16 cows from the high P group continued with their treatments for a second year. Also in the second year, 12 new cows were included in the low P group and 11 in the high P group. Thus, a total of 95 lactations with 65 cows were used in the trial, and 30 of the cows were used in both years. The dietary P was 0.38 and 0.48% during confinement feeding and approximately 0.31 and 0.44% during grazing for the low and high P treatments (dry basis). When all cows were used to obtain treatment means, milk yield for 308 d of lactation was 9131 and 8860 kg in yr 1, and 9864 and 9898 kg in yr 2 for the low P and high P groups, respectively. Blood serum inorganic P tended to be slightly lower for the low P than for the high P group during most of lactation; all concentrations (5.6 to 7.4 mg/dl) were within normal ranges. Reproductive measures were similar between groups in both years. When just the cows completing two lactations (N = 30) were evaluated, milk yield was 9072 and 8780 kg in yr 1 and 11,457 and 11,358 kg in yr 2 for the low P and high P treatments, respectively. Reducing dietary P from 0.48 to 0.38% for 2 yr did not impair milk production or reproductive performance.
(**Key words:** phosphorus, minerals, dairy cow, reproduction)

INTRODUCTION

Phosphorus supplementation of lactation diets is a routine practice. The average dietary P concentration in lactation diets in U.S. herds is approximately 0.48% of diet DM (32). This exceeds the amounts recommended by the NRC (26), and these recommendations are 10% greater than the 1978 NRC recommendations (25). Recently, several studies have suggested that P in lactation diets may be reduced from the current feeding level without affecting milk production. Brintrup et al. (4) fed dairy cows 0.33 or 0.39% P for 2 yr and found no difference in milk yield (25 kg/d) between treatments. Dhiman et al. (13) fed 0.39 or 0.65% P to midlactation cows for 12 wk and measured similar milk yield (24 kg/d). In a two-lactation study with cows receiving diets containing 0.24, 0.28, or 0.33% P, Valk and Ebek (38), concluded that 0.28% P was adequate for cows producing 9000 kg of milk per lactation. Although reducing P allowance is economically and environmentally sound, more data from long-term studies are needed. The objective of this 2-yr study was to measure performance of dairy cows when fed a diet with no supplemental P or a diet supplemented with P to a level that is commonly used by dairy producers.

MATERIALS AND METHODS

The protocol used in this experiment was approved by the Animal Care Committee of the College of Agricultural and Life Sciences, University of Wisconsin, Madison. The experiment included two dietary P concentrations, one that was close to the NRC (26) P recommendation (low), and one that was in excess of the NRC recommendation (high). The trial was carried out for 2 yr. Each year included a period of confinement feeding followed by a grazing period. In yr 1, 42 cows (20 primiparous) were assigned randomly to treatments within parity at calving (n = 21, including 10 primiparous animals in each group). In yr 2, 14 cows (seven primiparous) from the low P group and 16 cows (eight primiparous) from the high P group continued with their treatments for another full lactation. Twelve (six primiparous) new cows were added to the low P group and 11 (six primiparous) to the high P group. Thus, a total of 53 Holstein cows were used in yr 2. Over the 2 yr, 95 lactations (42 in yr 1 and 53 in yr 2; 32 from primiparous cows and 63 from multiparous cows) in-

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[1]Trade names and the names of commercial companies are used in this report to provide specific information. Mention of a trade name or manufacturer does not constitute a guarantee or warranty of the product by the USDA or an endorsement over products not mentioned.

volving 65 cows were used. Thirty of the cows were used in both years, including 15 primiparous cows in yr 1. For both years, cows in the low P group did not receive supplemental P, while cows in the high P group were fed monosodium phosphate and dicalcium phosphate. In yr 2, all cows were administered bST (Posilac; Monsanto Co., St. Louis, MO) every 2 wk beginning at wk 9 of lactation.

Cows (yr 1) calved during September and October and were housed in a free stall barn and fed a TMR in treatment groups until May. Beginning in May, pasture provided the majority of forage until the end of August, at which time all cows were dried off. In yr 2, cows again calved from September to October, except for 13 cows (six from the low P group and seven from the high P group) that calved later. All 13 cows were in their second year of the experiment. These cows were fed TMR individually in a tie stall barn throughout the lactation. In May all cows that calved during September and October were turned out to pasture. By that time, 95 and 81% in yr 1 and 90 and 75% in yr 2 of the grazing cows conceived for the low and high P groups, respectively. Grazing continued until the end of August, after which cows that were still milking were combined with the TMR-fed cows and all were offered the TMR until completion of the lactation. During the dry period in both years, all cows were fed a common dry cow diet.

Formulation of the TMR (Table 1) was the same for both years, and no change was made during the lactation. The low P diet contained no supplemental P, while the high P diet was formulated by adding monosodium phosphate and dicalcium phosphate to the low P diet in place of high moisture ear corn. The diets were offered once daily ad libitum (5 to 10% refusal).

Grazing cows were supplemented with concentrate mixes. Formulation of the supplemental mixes (Table 1) was the same for both years. The mix fed to the low P cows contained no supplemental P, while the mix fed to the high P cows contained dicalcium phosphate. The supplements were fed separately to each treatment group at a rate of 6.2 kg/d per cow in yr 1 and 7.9 kg/d per cow in yr 2 (DM basis). These amounts accounted for approximately 35 to 40% of total DMI based on average forage intake estimated from amounts of pasture grazed or milk energy secretion (unpublished data). The two dry cow diets contained no added P (Table 1). The far-dry diet was fed during the first 5 wk, and the close-up diet during the remaining 3 wk of the dry period.

The pasture contained primarily Kentucky bluegrass (*Poa pratensis*), quackgrass (*Elytrigia repens*), and smooth brome grass (*Bromus inermis*). In yr 1, forage in some paddocks also contained some clover (*Trifolium repens* and *Trifolium pratense*). Intensive rotational grazing was practiced by using electric fences to allocate a new grazing area daily. Cows from the two treatments grazed as a group. Grazing was available daily for all but 4 h, during which time cows were taken to the milking parlor. Following milking, cows were fed the supplements as a group according to treatments.

Cows were milked at 0500 and 1700 h, and milk yield was recorded. Milk samples were collected biweekly from two consecutive milkings and analyzed at the Ag-Source Milk Analysis Laboratory (Menomonie, WI) for fat, protein, lactose, total solids, and SCC with an infrared spectrophotometer with a B filter (Fossmatic 605; Foss Technology, Eden Prairie, MN); SNF was calculated as total solids minus fat.

Feeds offered and refused were recorded daily. Alfalfa silage, corn silage, and orts were sampled daily, frozen, and composited weekly. Grains (high moisture ear corn, soybean meal, and roasted soybeans) were sampled weekly. Dry matter contents of weekly samples were determined by oven-drying at 60°C for 48 h. Diet formulations (as-fed basis) were adjusted weekly for changes in DM content of the ingredients. Orts were used only for DMI calculations. Pasture forage was sampled during each grazing cycle (four cycles in each year) and dried at 60°C and composited. All dried samples were ground through a Wiley mill with a 1-mm screen (Arthur H. Thomas, Philadelphia, PA). Ground weekly grain samples were composited approximately every 4 wk. These composite grain samples and the ground weekly samples of alfalfa silage and corn silage were analyzed for DM (105°C), CP (LECO FP-2000 Nitrogen Analyzer, Leco Instruments, Inc., St. Joseph, MI), and NDF (heat stable α-amylase and Na_2SO_3 were used) and ADF (28); however, analyses of NDF and ADF in soybean meal and roasted soybeans were made only on one 4-wk composite sample.

For analysis of P, ground samples of alfalfa silage and corn silage were composited approximately every 4 wk, and grain samples approximately every 12 wk. These composites and the pasture forage samples were processed as described by Nelson and Satter (27) and analyzed for P content by direct current plasma emission spectroscopy by adapting the procedure described by Combs and Satter (10). A certified commercial P solution (VHG Labs, Inc., Manchester, NH) was used as a calibration standard. Accuracy of the analysis was assured by referring to additional commercial standards (Standard Reference Material 1570a—spinach leaves, and 8436—durum wheat flour; National Institute of Standards and Technology, Gaithersburg, MD) and by interlaboratory comparison of reference samples that resulted in differences <5%.

Chemical analyses were based on DM measurements made at 105°C. Nutrient content of the TMR, the sup-

Table 1. Ingredient and chemical composition of diets and supplements.

Item	During lactation				During the dry period	
	Diets during confinement		Supplements during grazing[1]			
	Low P	High P	Low P	High P	Far-dry	Close-up
	% of diet DM					
Ingredient						
Alfalfa silage	30.0	30.0	. . .	. . .	27.7	21.3
Corn silage	20.0	20.0	11.0	11.0	57.6	24.9
Grass hay	. . .	. . .	. . .	. . .	. . .	11.0
High moisture ear corn	28.4	28.0	74.7	74.1	4.8	12.5
Soybean meal	8.0	8.0	. . .	. . .	2.1	6.4
Soybean, roasted	12.0	12.0	10.6	10.6	2.2	2.0
Barley	. . .	. . .	. . .	. . .	5.3	13.7
Wheat middling	. . .	. . .	. . .	. . .	. . .	6.3
Monosodium phosphate	. . .	0.3	. . .	. . .	. . .	. . .
Calcium carbonate	1.1	1.0	2.8	1.7	. . .	. . .
Dicalcium phosphate	. . .	0.2	. . .	1.7	. . .	0.6
Salt	0.4	0.4	0.6	0.6	0.3	. . .
$MgSO_4$	. . .	. . .	. . .	. . .	. . .	1.3
Mineral and vitamin mix[2]	0.1	0.1	0.3	0.3	. . .	0.02
Chemical composition[3]						
Year 1						
CP, %	19.2	19.2	11.1	11.1	16.8	16.9
NDF, %	28.6	28.5	18.9	18.8	38.0	30.5
ADF, %	19.5	19.5	8.7	8.7	26.2	21.1
P, %	0.38	0.48	0.33	0.65	0.29	0.31
Year 2						
CP, %	19.7	19.6	12.1	12.1	13.9	17.1
NDF, %	28.3	28.3	16.5	16.4	37.3	28.1
ADF, %	19.8	19.8	7.4	7.4	26.5	22.1
P, %	0.38	0.48	0.33	0.65	0.29	0.31

[1]During grazing supplements were offered at 6.2 kg/d per cow in yr 1 and 7.9 kg/d per cow in yr 2 to provide approximately 35 to 40% of total DMI.

[2]Each kilogram contained 0.32 g of Se, 0.43 g of Co, 1.03 g of I, 13.35 g of Cu, 23.99 g of Fe, 51.00 g of Mn, 62.01 g of Zn, 7,000,000 IU of vitamin A, 2,222,000 IU of vitamin D, and 17,630 IU of vitamin E. The content of the supplemented nutrients in each kilogram of the diets during confinement were: Se, 0.32 mg; Co, 0.43 mg; I, 1.03 mg; Cu, 13.4 mg; Fe, 24.0 mg; Mn, 51.0 mg; Zn, 62.0 mg; vitamin A, 7000 IU; vitamin D, 2200 IU; and vitamin E, 17.6 IU.

[3]All composition values were computed from ingredient averages in Table 3 and from NRC (26) for grass hay, barley, and wheat middling.

plements for grazing cows, and the dry-cow diets was computed from the average nutrient content of the individual diet ingredients analyzed with the forementioned composite samples.

Blood was sampled periodically; sampling times fell within the following weeks of lactation: 1 to 5, 6 to 15, 16 to 25, 26 to 34, and 35 to 44 in yr 1, and 1 to 5, 6 to 12, 13 to 18, 19 to 25, 26 to 31, and 32 to 37 in yr 2. One blood sample was also obtained from each cow during each of the two dry periods. In yr 1 the average time of sampling was 43 d (SD 18) into the dry period, and in yr 2 it was 28 d (SD 20). Approximately 10 ml of blood was sampled from coccygeal vessels 3 h after feeding. The samples were centrifuged at 2200 × *g* for 15 min, and serum was analyzed for inorganic P concentration (molybdovanadate colorimetric procedure) for all samples and Ca (Lanthanum procedure) for some of the samples. These analyses were conducted by the Marshfield Laboratories (Marshfield, WI) according to AOAC (1).

Cows were weighed after milking at the beginning and end of lactation, and approximately every 4 wk during lactation. Body condition score was taken in yr 2 by one trained individual according to Wildman et al. (40), on approximately the same schedule as used for obtaining BW. Data related to reproduction and health were recorded. Estrus was monitored by the farm crew during the day and while cows were in the holding area prior to milking, using signs such as standing, mounting, and mucus discharge. Cows were inseminated at the first estrus after 52 d postpartum. The semen source and inseminator were not the same for all cows, but were equally distributed between treatments. Pregnancy was confirmed by rectal palpation. Conception rate at the first AI was the percentage of cows that conceived on first AI. Pregnancy rate was defined as the number of cows confirmed pregnant divided by the number of cows bred. Cows were identified as nonbreeders when they failed to become pregnant by 230 DIM. These cows were not used in the calculation of pregnancy rates.

Cows were dried off when they completed 44 wk of lactation or their milk yield dropped below 9 kg/d, or they were within 56 d of calving. As a normal herd management practice, cows were culled when they developed significant health problems. As a result, two cows in the high P group were culled in yr 2, one in wk 14, and one in wk 17. Five cows in each treatment in yr 1, and 11 and 8 cows in the low and high P groups in yr 2 were dried off during wk 31 to 44 (Table 2). To obtain 308-d lactation information for these cows, milk yields from the last five weekly averages were used to extrapolate by linear regression to generate estimates for the missing weeks.

Data were analyzed with the general linear models procedure of SAS (31). Each year was analyzed separately. Model 1 was used when all cows were included, and model 2 when only the cows that were used in the experiment in both years were included. These models are as follows:

$$Y = \mu + P + T + PT + E \quad [1]$$

$$Y = \mu + T + E \quad [2]$$

where Y = observation, μ = overall mean, P = parity (primiparous or multiparous), T = dietary treatment (P level), PT = interaction between P and T, and E = error term. The influence of parity was either nonsignificant or considered innocuous, and thus is not included in the discussion. Interaction between treatment and parity was not significant ($P > 0.10$) for any of the variables.

In addition, data on blood serum P concentration in yr 1 and yr 2 and Ca concentration in yr 2 were analyzed by using the mixed procedure of SAS (30). Treatment was the main plot, sampling time was the subplot, and parity was the random block. Categorical data on conception rate and pregnancy rate were analyzed for treatment effects using the FREQ procedure of SAS (31) with a chi-square test.

RESULTS AND DISCUSSION

Nutrient content of ingredients (Table 3) was consistent within and between years. Dietary P content was computed from P content of ingredients and was 0.38 and 0.48% of diet DM during confinement feeding for the low and high P diets for both years (Table 1). The corresponding concentrations during grazing were 0.31 and 0.44%, and these were calculated from the P content of the supplements and the pasture, assuming that 40% of the total DMI was provided by the supplements and 60% by pasture. The content of P in the two dry-cow diets was 0.29 and 0.31%. Based on NRC (26) tabular values, dietary Ca content was 0.77%, and NE_L was 1.68 Mcal/kg for the two diets fed during confinement.

The concentration of inorganic P in blood serum appeared slightly lower for cows fed the low P diet than for those fed the high P diet (Figure 1a); means were 6.1 versus 6.7 mg/dl (SE 0.3, $P = 0.11$) for yr 1 and 6.2 versus 6.4 mg/dl (SE 0.2, $P = 0.13$) for yr 2. The concentrations were similar at the end of lactation. All concentrations (5.6 to 7.4 mg/dl) were within the normal range (4 to 8 mg/dl) typically seen in lactating cows (15). Serum concentrations of inorganic P during the dry period increased compared with the last measurement during lactation but were similar between treatments, reflecting that cows were fed the same diets during this period. The trend in P concentration during lactation was not consistent between the 2 yr. An in-

Table 2. Number of cows that left the experiment before completing 44 wk of lactation.

	Week of lactation									
Dietary P[1]	14	17	31	33	40	41	42	43	44	Total
Year 1										
Low	...	...	...	...	...	1[y]	3[d,y,y]	1[d]	...	5
High	...	...	1[m]	...	1[d]	1[y]	1[d]	2[d]	...	6
Year 2										
Low	...	...	...	1[h]	2[d,y]	2[d]	1[d]	4[d,d,d,y]	1[d]	11
High	1[h]	1[m]	...	1[h]	3[d]	1[d]	1[d]	1[d]	1[d]	10

[d,h,m,y]Reasons for termination: d = dried off to allow for a 56-d dry period; h = health problems; m = mastitis; y = milk yield < 9 kg/d.

[1]Phosphorus content was 0.38 and 0.48% during confinement feeding for approximately two-thirds of lactation and 0.31 and 0.44% during grazing for the remainder of lactation for the low and high P diets, respectively.

Table 3. Analyses of dietary ingredients.[1]

	Year 1					Year 2				
Feed	DM	CP	NDF	ADF	P	DM	CP	NDF	ADF	P
	(%)									
Alfalfa silage										
x̄	35.6	21.9	40.7	36.1	0.334	36.4	22.0	43.3	38.8	0.336
SD	4.1	1.9	4.5	4.2	0.036	6.2	1.8	3.7	3.4	0.021
Corn silage										
x̄	32.2	7.3	42.4	27.1	0.224	31.6	8.1	39.8	25.7	0.232
SD	2.1	1.1	3.6	2.8	0.017	4.3	1.0	3.4	2.1	0.023
HMEC[2]										
x̄	68.7	8.0	14.5	5.9	0.307	69.3	9.2	12.7	4.9	0.316
SD	2.0	0.7	4.6	2.5	0.019	2.5	0.5	3.4	1.9	0.017
Soybeans[3]										
x̄	97.4	40.9	24.9	8.2	0.700	95.6	41.4	24.4	8.1	0.694
SD	1.1	1.1	. . .	. . .	0.020	2.7	4.1	. . .	. . .	0.035
Soybean meal										
x̄	89.8	50.1	9.5	7.4	0.705	90.1	48.6	9.6	7.5	0.693
SD	0.6	2.3	. . .	. . .	0.018	0.6	2.7	. . .	. . .	0.025
Pasture										
Grass	. . .	23.0	46.3	24.8	0.29	. . .	46.5	28.9	46.5	0.36
Mixed[4]	. . .	23.5	42.3	30.6	0.32	. . .	. . .	. . .	. . .	. . .

[1]For analysis of DM, CP, NDF, and ADF, weekly composite samples of forages (alfalfa silage and corn silage) and 4-wk composite samples for grains (high moisture ear corn, roasted soybeans, and soybean meal) were used. For analysis of P, composites were made approximately every 4 wk for forages and approximately every 12 wk for grains. This schedule of compositing was followed throughout the trial in each year. A total of 58 samples each for alfalfa silage and corn silage and 14 samples each for high moisture ear corn, roasted soybeans, and soybean meal were analyzed for DM, CP, NDF, and ADF in each year. Thirteen samples of each forage source and four samples of each grain source were analyzed for P in each year. One composite sample of pasture forage was analyzed in each year.

[2]High moisture ear corn.

[3]Roasted.

[4]The pasture forage consisted on average of 74% grasses and 26% red clover and white clover.

creasing trend was noted in a separate study (41). Similarly, serum concentration of inorganic P was lower for cows receiving low P diets than for those receiving high P diets in other studies (13, 17). In ruminants, the concentration of inorganic P in blood serum appears to reflect the intake of P (36), but only extremely low serum concentrations (4 <mg/dl) may indicate deficiency of P (15). According to this criterion, cows fed the low P diet in our experiment were not deficient in P. Measured once at about 209 DIM (SD 15) in yr 1, mean serum concentrations of Ca were similar (9.1 and 9.4 mg/dl; SE 0.1, $P > 0.05$) between treatments. Measured more frequently in yr 2 at wk 1 to 5, 6 to 12, 13 to 18, 19 to 25, 31 to 36, and 32 to 37, Ca concentrations again were similar (Figure 1b), with means being 9.3 and 9.0 mg/dl (SE 0.2, $P > 0.1$). Serum Ca concentration in cattle averages 10 mg/dl (34) and has been shown to increase during P deficiency (3).

Cows in the low P group were detected in estrus 8.8 d later ($P = 0.11$) in yr 1 but 12.9 d earlier ($P = 0.28$) in yr 2 than cows in the high P group. The year-to-year differences were likely a result of random error. The two groups were serviced with the first AI at similar DIM (Table 4) for both years. Days open were similar. Conception rate at the first AI was not consistently different between groups from year to year. Pregnancy rates at 120 and 230 DIM were similar between treatment groups. Services per conception were similar in yr 1 but tended to be lower ($P = 0.13$) for the low P group than the high P group in yr 2. For cows that were used in the experiment in both years, efficiency of reproduction over the 2 yr was as good for the low P group as for the high P group (Table 5).

We present results pertaining to reproductive performance of the cows in this experiment, realizing that insufficient numbers preclude drawing conclusions about any kind of relationship between dietary P and reproductive performance. These data can be useful, however, when combined with results from similar experiments. Based on the variances (s^2) in days to first estrus, days open, and services per conception obtained in this experiment, the minimum number of animals per treatment needed to detect a 10% difference in a reproductive measure at a 95% confidence level is estimated (Table 6). These estimates vary among measures and between trials in the 2 yr, but average about 250.

Thus, given similar variation, a sample size of about 250 cows would be needed to show a 10% difference between treatments. Using this approach, we summarize results from several other studies (4, 5, 7, 8, 11, 35, 41) and the present study. Together, these experiments used a total of 785 cows, or about 392 cows per treatment. Not all trials reported on all measures of reproductive performance, so each measure is based on something less than 392 cows. Dietary P concentration ranged from 0.32 to 0.40% of diet DM for low P groups across trials, and from 0.39 to 0.61% for high P groups. Means for each group from all the experiments were evaluated using SAS (31) by fitting into a one-way classification model utilizing a weighting factor based on the number of cows in each experiment. The following means for the low P group and the high P group were obtained: days to first estrus, 46 and 48 (SE 4.2, $P > 0.1$); days to first AI, 73 and 76 (SE 3.3, $P > 0.1$); days open, 96 and 100 (SE 4.9, $P > 0.1$); services per conception, 1.8 and 1.9 (SE 0.2, $P > 0.1$); and pregnancy rate, 0.87 and 0.86 (SE 0.02, $P > 0.1$). Feeding low P had no adverse effect on reproductive performance. In the study of Call et al. (7), dietary P as low as 0.24% did not impair reproductive performance, although it did decrease milk yield and feed intake. The study of Valk and Ebek (38), where dietary P of 0.24, 0.28, or 0.33% was fed for two lactations, also indicated no effect of dietary P content as low as 0.24% on reproductive performance. Reproduction is unlikely to be impaired unless dietary P concentrations are extremely low (<0.25%). At dietary concentrations below 0.25%, rumen microbes may have inadequate amounts of P for maximum growth (14). This can result in less microbial protein and possibly lowered ration digestibility. Thus, under these extreme conditions, low dietary P could conceivably have an indirect effect on reproductive performance through impact on the cow's energy balance (12). Impaired reproductive performance does occur in beef cows fed extremely low dietary P, but this probably is related to the malnutrition that can result from impaired ruminal fermentation. Dairy cows are normally not subjected to such diets. On the other hand, feeding P in excess of NRC (26) recommendations does not result in better reproductive performance (7, 29).

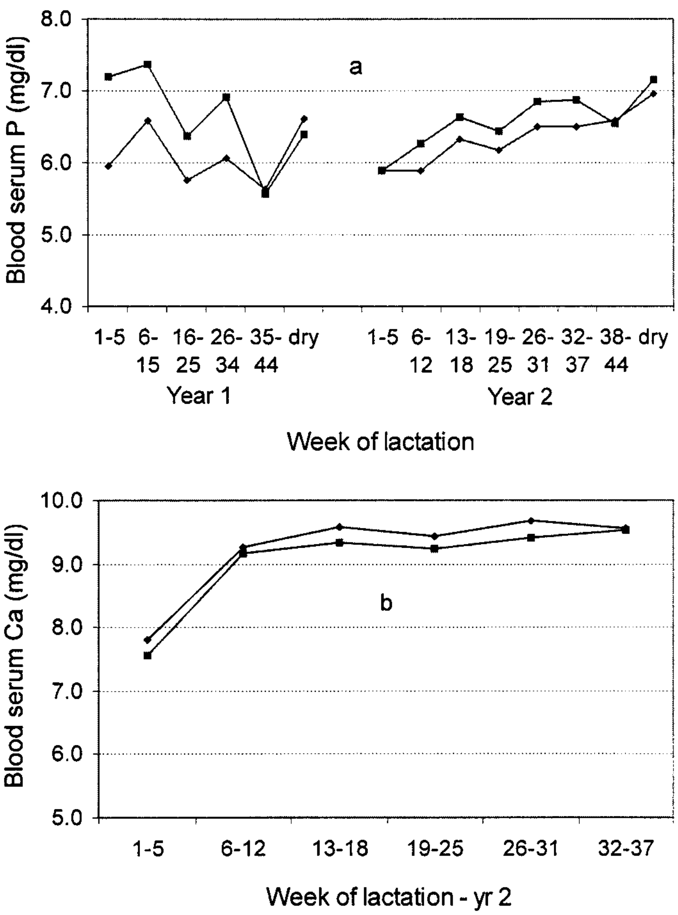

Figure 1. Concentration of inorganic P (a) and Ca (b) in blood serum of cows fed diets containing low (0.38 to 0.31%, ◆) or high (0.48 to 0.44%, ■) P. Means for P were 6.1 versus 6.7 mg/dl (SE 0.3, $P = 0.11$) in yr 1 and 6.2 versus 6.4 mg/dl (SE 0.2, $P = 0.13$) in yr 2 for the low P diet compared with the high P diet. Means for Ca in yr 2 were 9.3 and 9.0 mg/dl (SE 0.2, $P > 0.1$) for the low and high P diets, respectively.

The recorded health problems (Tables 4 and 5) showed no apparent association with treatments, except for foot rot, which occurred more times in the high P group in both years. In a separate study (41), an opposite trend was recorded. The limited number of cows used in these experiments prevents drawing firm conclusions about treatment effect on the incidence of health problems.

Averages of DMI during confinement feeding were similar between groups in both years (Table 7), indicating that feeding P at 0.38 or 0.48% of the diet had no effect on ad libitum feed intake. With beef cows (2, 6) and lambs (37), diets are usually much lower in P than diets for lactating dairy cows, and decreased feed intake has been one of the major consequences of P deficiency. Accordingly, the lack of treatment difference in DMI suggests that cows receiving 0.38% P were not deficient in P. Call et al. (7) reported that dietary P of 0.32 or 0.42% did not affect DMI, but 0.24% dietary P decreased DMI of lactating dairy cows.

Milk yields for the entire lactation were not different between treatments in either year (Table 7), and at no time during lactation did the high P group appear to yield more milk than the low P group (Figure 2). Grazing contributed to the decline of the lactation curves during the latter part of the lactation. Mean milk fat percentage, fat yield, and 3.5% FCM yield

Table 4. Reproductive and health measures of lactating cows fed diets containing low or high P in a 2-yr study.[1]

	Year 1				Year 2			
Measure	Low P[2] (n = 21)	High P[2] (n = 21)	SEM	*P*	Low P[2] (n = 26)	High P[2] (n = 27)	SEM	*P*
Days to first estrus	52.2	43.4	3.8	0.11	47.8	60.7	8.4	0.28
Days to first AI	76.4	76.8	4.1	0.93	65.6	72.2	5.7	0.42
Days open[3]	115	120	11	0.76	103	105	13	0.94
Conception rate at first AI, %	28.6	42.9	. . .	0.33	42.3	28.0	. . .	0.28
Pregnancy rate								
At 120 DIM, %	57.1	52.4	. . .	0.76	61.5	50.0	. . .	0.40
At 230 DIM, %	95.2	90.5	. . .	0.55	96.0	86.4	. . .	0.24
Services/conception[3]	2.5	2.6	0.4	0.80	1.6	2.1	0.2	0.13
Abortions[4]	2	2	. . .	. . .	1	1	. . .	. . .
Incidence of foot rot[4]	1	6	. . .	. . .	3	4	. . .	. . .
Off-feed[4]	5	2	. . .	. . .	2	1	. . .	. . .
Incidence of mastitis[4]	17	14	. . .	. . .	22	23	. . .	. . .

[1]Includes all cows, some of which completed both lactations. Some cows were brought into the second lactation to replace cows that were culled after the first year of the experiment.

[2]Phosphorus content was 0.38 and 0.48% during confinement feeding for approximately two-thirds of the lactation and 0.31 and 0.44% during grazing for the remainder of lactation for the low and high P diets, respectively.

[3]Includes only the cows that ultimately became pregnant.

[4]Total number of occurrences. If one animal had multiple occurrences, the actual occurrences were counted. Drug treatment was used to qualify an occurrence of mastitis. Multiple treatments within a period of 1 mo were counted as one occurrence.

did not differ between treatments in either year. Milk protein percentage was lower ($P = 0.06$) for low P than for high P in yr 1, but did not differ in yr 2. The difference in yr 1 was consistent throughout the lactation (Figure 3). Milk protein yield did not differ between treatments in either year. The content of lactose, SNF, or SCC of milk was not different. Changes in BW during lactation were similar ($P = 0.24$) in both years, and

Table 5. Reproductive and health measures of lactating cows fed diets containing low or high P for two consecutive lactations.[1]

	Year 1				Year 2			
Measure	Low P[2] (n = 14)	High P[2] (n = 16)	SEM	*P*	Low P[2] (n = 14)	High P[2] (n = 16)	SEM	*P*
Days to first estrus	49.4	42.0	4.8	0.29	48.7	73.6	10.0	0.09
Days to first AI	75.2	75.2	4.4	0.99	67.2	80.7	7.4	0.21
Days open[3]	116	127	14	0.55	105	110	17	0.83
Conception rate at first AI, %	28.6	37.5	. . .	0.61	42.9	12.5	. . .	0.06
Pregnancy rate								
At 120 DIM, %	64.3	56.3	. . .	0.65	64.3	43.8	. . .	0.26
At 230 DIM, %	100	100	. . .	. . .	85.7	56.3	. . .	0.08
Services/conception[3]	2.4	2.6	0.4	0.70	1.5	2.0	0.2	0.13
Abortions[4]	1	1	. . .	. . .	0	1	. . .	. . .
Incidence of foot rot[4]	0	6	. . .	. . .	1	4	. . .	. . .
Off-feed[4]	3	2	. . .	. . .	2	1	. . .	. . .
Incidence of mastitis[4]	10	9	. . .	. . .	16	17	. . .	. . .

[1]Includes only those cows that were on the experimental treatments for both lactations.

[2]Phosphorus content was 0.38 and 0.48% during confinement feeding for approximately two-thirds of the lactation and 0.31 and 0.44% during grazing for the remainder of lactation for the low and high P diets, respectively.

[3]Includes only the cows that ultimately became pregnant during the experiment.

[4]Total number of occurrences. If one animal had multiple occurrences, the actual occurrences were counted. Drug treatment was used to qualify an occurrence of mastitis. Multiple treatments within a period of 1 mo were counted as one occurrence.

Table 6. Minimum number of animals per treatment needed to detect a 10% difference in reproductive measures between treatments at $P = 0.05$.

	Year 1				Year 2				$\bar{x}$
Measure	S^2	$\bar{x}^1$	$\bar{x} \pm 10\%$	n^2	s^2	$\bar{x}$	$\bar{x} \pm 10\%$	n^2	n
Days to first estrus	299	43.4	43.4 ± 4.3	127	1312	47.8	47.8 ± 4.8	459	293
Days open	2650	115	115 ± 12	160	2958	103	103 ± 10	223	192
Services/conception	2.96	2.5	2.5 ± 0.3	379	0.86	1.6	1.6 ± 0.2	269	324
Average	. . .	. . .	. . .	222	. . .	. . .	. . .	317	270

[1]Lower mean between treatments in trial.

[2]$n = (2 \times t_{0.05}^2 \times s^2)/(\bar{x} \pm 10\%)^2$, ($t_{0.05}$ approximates 2).

BCS at the end of lactation in yr 2 also was similar ($P = 0.42$).

The performances of cows that were on the two P treatments for two consecutive lactations are given in Table 8. Milk yield was unaffected by treatments. Milk protein content appeared to be lower for low P cows than for high P cows for both years, but the difference was not significant. Influence of dietary P on milk protein concentration has been inconsistent. In the study of De Boer et al. (11) protein percentage of milk was lower for 0.34% dietary P than for 0.51 and 0.69% P. Call et al. (7) also reported a lower milk protein percentage when 0.24% rather than 0.32% P was fed, but similar percentages of milk protein were reported for 0.32 and 0.42% dietary P. Milk protein percentage in the study of Dhiman et al. (13) was numerically lower when the diet contained 0.35% P than 0.69% P. Other studies (4, 5, 9, 38) showed no difference in milk protein concen-

Table 7. Lactation performance of cows fed diets containing low or high P in a 2-yr study.[1]

	Year 1				Year 2			
Item	Low P[2] (n = 21)[3]	High P[2] (n = 21)[3]	SEM	*P*	Low P[2] (n = 26)[3]	High P[2] (n = 27)[3]	SEM	*P*
DMI, kg/d[4]	20.7	20.4	. . .	. . .	23.2	23.4	. . .	. . .
Milk, kg/308 d	9131	8860	283	0.50	9864	9898	340	0.94
3.5% FCM, kg/d	29.6	29.3	0.9	0.85	34.1	33.9	1.0	0.89
Milk fat								
%	3.46	3.58	0.09	0.37	3.78	3.65	0.10	0.38
kg/d	1.02	1.03	0.03	0.85	1.23	1.20	0.04	0.68
Milk protein								
%	3.05	3.16	0.04	0.06	3.14	3.14	0.04	0.96
kg/d	0.91	0.93	0.02	0.73	1.01	1.03	0.03	0.73
Milk lactose, %	4.84	4.86	0.04	0.76	4.81	4.87	0.05	0.44
Milk SNF, %	8.62	8.73	0.06	0.17	8.72	8.77	0.07	0.65
Milk SCC, 10^3/ml	301	347	74	0.66	230	407	82	0.14
BW during lactation								
Beginning[5], kg	564	544	11	0.21	566	587	16	0.36
End, kg	606	601	11	0.76	601	623	14	0.27
Change, g/d	130	180	30	0.24	135	144	37	0.86
BCS[6] during lactation								
Beginning[5]	. . .	. . .	. . .	. . .	3.31	3.46	0.11	0.33
End	. . .	. . .	. . .	. . .	3.46	3.47	0.10	0.89
Change	. . .	. . .	. . .	. . .	0.15	0.02	0.11	0.42

[1]Includes all cows, some of which completed both lactations. Some cows were brought into the second lactation to replace cows that were culled after the first year of the experiment.

[2]Phosphorus content was 0.38 and 0.48% during confinement feeding for approximately two-thirds of the lactation, and 0.31 and 0.44% during grazing for the remainder of lactation for the low and high P diets, respectively.

[3]Includes 11 primiparous cows for the low P group and nine primiparous cows for the high P group in yr 1 and six primiparous for each group in yr 2.

[4]Based on measurements during confinement feeding that included the time from parturition to the time cows went onto pasture (between 28 to 35 wk into lactation), and some time toward the end of lactation in yr 2.

[5]Beginning measurements were obtained at an average of 28 DIM for yr 1 and 18 for yr 2.

[6]Body condition score (5-point scale where 1 = thin to 5 = fat).

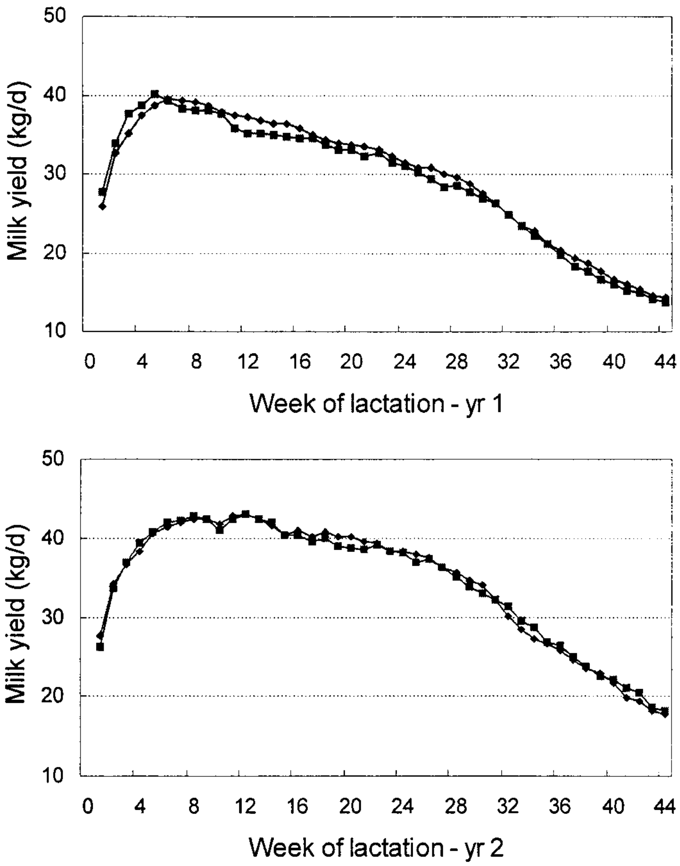

Figure 2. The lactation curve of cows fed diets containing low (0.38 to 0.31%, ◆) or high (0.48 to 0.44%, ■) P.

tration due to dietary P content. Given the inconsistency of results regarding a relationship between dietary P and percentage of milk protein, future studies should provide opportunities to measure a possible relationship. Because P is a part of the casein micelle (16), it is conceivable that serum P concentration could have some influence on milk protein content. Alternatively, De Boer et al. (11) suggested that phosphate supplements may enhance microbial protein synthesis through a buffering and osmotic effect in the rumen. The content of other milk components did not differ between treatments. Both groups of cows gained approximately 100 kg of BW over the 2-yr period and were similar in mean body condition score at the end of lactation in yr 2.

The lack of difference in lactation performance due to dietary P content is consistent with results of several other long- (>1 yr) (4, 35, 38) or short-term (12 wk) (13) studies. The dietary P in the first three studies was 0.33 versus 0.37%, 0.4 versus 0.6%, and 0.39 versus 0.65%, respectively. The study of Valk and Ebek (38) compared P concentrations of 0.24, 0.28, and 0.33%. While the differences in P concentration between treatments were small and the dietary P concentrations were extremely low for the studies of Brintrup et al. (4) and Valk and Ebek (38), the amounts of P used in the other two studies were higher than generally recommended (26). The concentrations used in the present study (0.38 and 0.48%) fall within the range of 0.24 to 0.65% covered by these studies. Together, these studies suggest that dietary P at 0.33 to 0.37% of diet DM meets the requirement of moderate to high producing cows. Can the amount of dietary P be lowered further? Call et al. (7) reported that reducing dietary P from 0.42 to 0.32% did not affect milk yield, but a further reduction to 0.24% decreased milk yield. Valk and Ebek (38) concluded that 0.28% dietary P is adequate for cows producing 9000 kg of milk per lactation, whereas 0.24% is definitely inadequate. Kincaid et al. (17) reported a lower milk yield when cows were fed 0.30% P than those fed 0.54% P (27.5 vs. 29.1 kg/d). Recently Wu et al. (41) reported that milk yields were similar (11,226 vs. 11,134 kg/308 d) for cows fed either 0.40 or 0.49% P, but milk yield was reduced (10,790 kg/308 d) when only

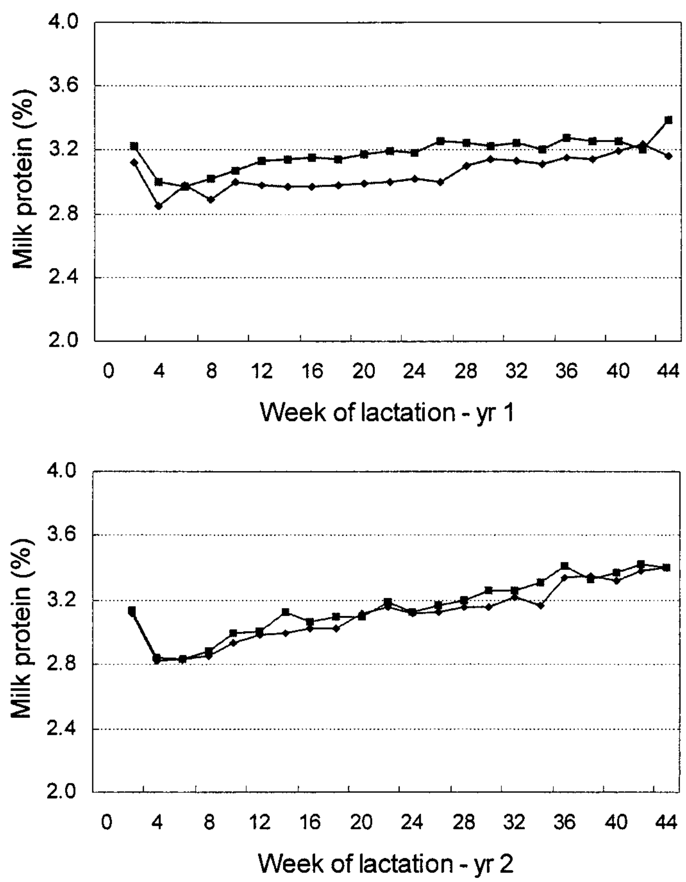

Figure 3. Concentration of protein in milk of cows fed diets containing low (0.38 to 0.31%, ◆) or high (0.48 to 0.44%, ■) P.

Table 8. Lactation performance of cows fed diets containing low or high P for two consecutive lactations.[1]

	Year 1				Year 2			
Item	Low P[2] (n = 14)[3]	High P[2] (n = 16)[3]	SEM	*P*	Low P[2] (n = 14)[3]	High P[1] (n = 16)[3]	SEM	*P*
Milk, kg/308 d	9072	8780	326	0.53	11,457	11,358	404	0.86
Milk, kg/d	29.5	28.5	1.1	0.45	37.2	36.9	1.3	0.87
3.5% FCM, kg/d	29.5	29.0	1.0	0.77	39.2	38.1	1.08	0.47
Milk fat								
%	3.46	3.63	0.67	0.30	3.66	3.63	1.20	0.85
kg/d	1.02	1.03	0.04	0.84	1.39	1.34	0.04	0.47
Milk protein								
%	3.05	3.15	0.05	0.14	3.06	3.15	0.05	0.23
kg/d	0.91	0.91	0.03	0.89	1.16	1.17	0.03	0.88
Milk lactose, %	4.84	4.86	0.04	0.42	4.77	4.79	0.05	0.74
Milk SNF, %	8.61	8.75	0.06	0.13	8.60	8.71	0.08	0.31
Milk SCC, 10^3/ml	277	308	68	0.75	259	373	102	0.44
BW during lactation								
Beginning,[4] kg	555	545	14	0.61	633	627	17	0.81
End, kg	605	607	15	0.93	651	647	14	0.85
Change, g/d	160	190	35	0.54	51	66	46	0.82
BCS[5] during lactation								
Beginning[4]	. . .	. . .	. . .	. . .	3.46	3.22	0.13	0.19
End	. . .	. . .	. . .	. . .	3.52	3.53	0.11	0.93
Change	. . .	. . .	. . .	. . .	0.05	0.31	0.13	0.17

[1]Includes only those cows that were on the experimental treatments for both lactations.

[2]Phosphorus content was 0.38 and 0.48% during confinement feeding for approximately two-thirds of lactation and 0.31 and 0.44% during grazing for the remainder of lactation for the low and high P diets, respectively.

[3]Numbers of primiparous and multiparous cows were equal in each group for yr 1 and all cows were multiparous in yr 2.

[4]Beginning measurements were obtained at an average of 28 DIM for yr 1 and 18 DIM for yr 2.

[5]Body condition score (5-point scale where 1 = thin to 5 = fat).

0.31% P was fed. The reduction in milk yield occurred during the latter part of lactation. Thus, it does not seem likely that dietary P can be reduced much below 0.32% without risking a reduction in milk production. Based on all these studies, dietary P < 0.32% is too low, and concentrations between 0.33 to 0.37% appear adequate for moderate to high production levels (7500 to 9000 kg per lactation), but 0.38 to 0.40% might be prudent for very high producing cows (>10,000 kg per lactation).

The concentration of 0.38% dietary P is lower than the value of 0.41 and 0.48% suggested by NRC (26) for high producing and early lactation cows, respectively, but higher than the NRC recommendation (as low as 0.28%) for late lactation and low producing cows. In our study neither the reproduction data nor the lactation data suggest that it is necessary to feed diets especially high in P in the first weeks of lactation to compensate for low feed intake in early lactation. Bone P and Ca are mobilized together in early lactation, and the mobilized P is an important source of P during this period. This source of P can compensate for the reduced P intake due to low feed consumption. De Boer et al. (11) reported that the balance of P in cows fed 0.34% dietary P was slightly negative for wk 5 to 7 of lactation, but positive for wk 17 to 20. The balance was all positive in midlactation cows fed diets containing 0.30, 0.41, or 0.56% P (24). That cows in our study fed the low P diet for 2 yr performed as well as those fed the high P diet indicates that 0.38% P may be adequate for the long term. Although not analyzed in our experiment, bones from cows fed 0.35 or 0.45% dietary P for 1 to 2 yr did not differ in content of total ash or P in the study of Brodison et al. (5). Dairy diets consisting of alfalfa, corn silage, corn, and soybean meal, and containing 16 to 18% protein will typically contain 0.35 to 0.38% P without any added P source, meaning that many dairy diets can be formulated without supplemental P. A negative balance of P may occur during early lactation with diets containing 0.35 to 0.38% P, but correction of the balance in late lactation should occur. Formulating lactation diets with much less than 0.30% P is difficult, and in all probability will be more expensive than diets composed of common ingredients.

The NRC (26) uses 50% as the availability value of P in the digestive tract in deriving the P requirement of lactating cows. This compares to a value of 55% used in the previous version of NRC (25). It is difficult to accurately measure P availability in the gut because of the large quantity of P recycled into the stomach via saliva. Experiments (18, 19, 20, 21, 22, 23, 39) with designs that permitted reasonable estimates of true availability suggest that an average availability value of 70% for dietary P fed to meet the requirement is realistic. Efficiency of absorption of P varies with P intake. Shirazi-Beechey et al. (33) suggested that a low intake of P stimulates P absorption by increasing the V_{max} of the active transport system at the proximal small intestine. Phosphorus consumed in excess of requirements is excreted in feces, resulting in low apparent digestibilities when high P diets are fed.

CONCLUSIONS

This study summarized 95 lactations involving 65 cows, including 30 cows that were used for two consecutive lactations. Cows in this study fed diets with no supplemental P (0.38% dietary P during confinement feeding for approximately two-thirds of the lactation and 0.31% P during grazing for approximately one-third of the lactation) performed as well as cows receiving supplemental P (0.48% P during confinement feeding and 0.44% P during grazing). Blood serum P concentrations were slightly lower, but within normal ranges when the low P diet was fed. Cows that received the low P diet in the second year performed normally. Phosphorus at 0.38 to 0.40% of diet DM should be adequate for cows producing ~11,400 kg/308 d. Currently, dairy producers tend to feed P in excess of NRC recommendations and certainly in excess of the dietary P concentration used in this study.

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